THE

QUARTERLY JOURNAL

OF THE

GEOLOGICAL SOCIETY OF LONDON.

EDITED BY

THE ASSISTANT-SECRETARY OF THE GEOLOGICAL SOCIETY.

Quod si cui mortalium cordi et curæ sit non tantum inventis hærere, atque iis uti, sed ad ulteriora penetrare; atque non disputando adversarium, sed opere naturam vincere; denique non belle et probabiliter opinari, sed certo et ostensive scire; tales, tanquam veri scientiarum filii, nobis (si videbitur) se adjungant. —*Novum Organum, Præfatio.*

VOLUME THE SIXTY-FIFTH.

1909.

LONDON:

LONGMANS, GREEN, AND CO.

PARIS: CHARLES KLINCKSIECK, 11 RUE DE LILLE.

SOLD ALSO AT THE APARTMENTS OF THE SOCIETY.

MDCCCCIX.

List

OF THE

OFFICERS

OF THE

GEOLOGICAL SOCIETY OF LONDON.

Elected February 19th, 1909.

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Prof. William Johnson Sollas, LL.D., Sc.D., F.R.S.

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George William Young.

Assistant-Secretary, Clerk, Librarian, and Curator.

L. L. Belinfante, M.Sc.

Assistants in Office, Library, and Museum.

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Prof. S. H. Cox.
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Mr. A. Harker.
Mr. R. S. Herries.
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Dr. J. E. Marr.
Dr. G. T. Prior.
Dr. A. Strahan.
Prof. W. W. Watts.
Mr. H. Woods.

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Corrigenda.

Page lvii, line 7 from the bottom, *for* 'F. S.,' *read* 'T. S.'
Page 217, line 9 from the top, *after* 'gasteropod,' *add* 'referred to the genus.'
Page 326, line 2 from the top, *for* 'prying,' *read* 'prizing.'
Page 337, line 13 from the top, *for* 'ragged' *read* 'rugged.'
Page 339, line 17 from the top, *for* 'p. 325,' *read* 'p. 327.'

Vol. LXV. FEBRUARY 24TH, 1909. **No. 257.**
PART 1.

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OF THE

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EDITED BY

THE ASSISTANT-SECRETARY.

[With Three Plates, illustrating Papers by Mr. E. A. N. Arber, Mr. H. J. L. Beadnell, and Dr. A. R. Dwerryhouse.]

C. A. White

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STANDING PUBLICATION COMMITTEE.

[The above Committee is to be appointed by the new Council in the ordinary course on February 24th.]

EVENING MEETINGS OF THE GEOLOGICAL SOCIETY TO BE HELD AT BURLINGTON HOUSE.

Session 1908–1909.

1909.		
Wednesday,	March	10*—24
„	April	7*—28
„	May	12*—26
„	June	16*

[*Business will commence at Eight o'Clock precisely each Evening.*]

The dates marked with an asterisk are those on which the Council will meet.

PROCEEDINGS

OF THE

GEOLOGICAL SOCIETY OF LONDON.

SESSION 1908–1909.

November 4th, 1908.

Prof. W. J. Sollas, LL.D., Sc.D., F.R.S., President,
in the Chair.

William Frederick Clark, The Poplars, Aldridge, near Walsall; Leonard Clifford Green, Lecturer on Geology & Mineralogy in the Brisbane Technical College, Brisbane (Queensland); J. Wilfrid Jackson, Assistant-Keeper in the Manchester Museum, 113 Sewerby Street, Alexandra Park, Manchester; and James Leonard Maxim, B.Sc., Lecturer in Geology in the Rochdale Technical & Secondary School, 404 West View, Whitworth Road, Rochdale (Lancashire), were elected Fellows of the Society.

The List of Donations to the Library was read.

The President announced that the result of the communication addressed to the Foreign and Colonial Fellows of the Society, with regard to the Admission of Women, was as follows:—

Papers sent out	313
Answers received	124

Analysis of Replies.

1. Are you in favour of the Admission of Women to the Geological Society of London?

Yes	97	
No	27	
		124

2. Are you in favour of the Admission of Women as Fellows, or as Associates only? The 97 in favour of admission voted:—

As Fellows	70	
As Associates	25	
Not specified	2	
		97

3. If there should not be a majority of those voting in favour of Women as Fellows, are you in favour of their Admission as Associates?

Yes	93	
No	3	
Not specified	1	
		97

The Secretary read a note from the Under Secretary of State for the Colonies, embodying the following extracts from a Report on a Scientific Expedition to the Falkland Islands (October 1907–February 1908) by Dr. Carl Skottsberg:—

'We here [in the East Falkland] met with a most interesting field for our work, as we discovered that the so-called "Lafonia," that is, the south-western part of the island, belongs to a geological formation different from the rest, namely, the Permo-Carboniferous Period. ....

'The Devonian formation, which constitutes the larger part of the islands, was closely surveyed, and fossils were discovered in several new localities. The stratigraphical and tectonic conditions, especially on the West Island, proved to be of interest and value for the explanation of its present topographical features. Mr. T. Halle's most important task was to solve the question of the supposed occurrence of Permo-Carboniferous layers of Gondwana type. Some fragmentary plant-fossils, collected in 1902 during the Swedish Antarctic Expedition, were described by Prof. A. G. Nathorst under the name of *Phyllotheca* sp., and compared with a species from the *Glossopteris*-flora; but, because of the poor condition of the samples, his determination remained doubtful. Mr. Halle has now been able to solve the question. Fossils, principally leaves of *Glossopteris*, occur in many places, and it is evident that the whole southern part of the East Falkland, south of Wickham Heights, belongs to the Gondwana System. At the base of the *Glossopteris*-Series he discovered a clay-stone, containing blocks, apparently of glacial origin, which undoubtedly corresponds with the moraines from other parts of Gondwanaland. This discovery is of very great importance. The old Permo-Carboniferous ice-age has been known before, from discoveries made in India, Australia, Africa, and San Luis in Argentina; its boundary is now moved 17 degrees farther south.

'Of more recent formation, an interesting forest-bed, discovered on West Point Island by Mr. A. E. Felton, was made an object of special investigation. The bed, which contains great quantities of large trunks, is covered by old "flowing-soil," formed during the period of solifluction, of which we have such striking monuments in the famous stone-runs studied by Dr. Andersson and myself during the Swedish Antarctic voyage. The bed is probably of pre-Glacial age. After having been worked out, the collections will give important information as to the phyto-geographical and climatological conditions during the early Quaternary. We also paid attention to the other Pleistocene deposits, as well as to the question of changes of the level of the islands, supposed to have occurred in the latest period. The result of these researches, however, cannot be communicated until the observations and collections have been thoroughly studied.'—[Dated Punta Arenas, April 1st, 1908.]

The following communications were read:—

1. 'The Relations of the Nubian Sandstone and the Crystalline Rocks south of the Oasis of Kharga (Egypt).' By Hugh John Llewellyn Beadnell, F.G.S. (late of the Geological Survey of Egypt).

2. 'On the Fossil Plants of the Waldershare and Fredville Series of the Kent Coalfield.' By E. A. Newell Arber, M.A., F.L.S., F.G.S.

The following specimens, lantern-slides, and sections were exhibited:—

Lantern-slides, exhibited by H. J. L. Beadnell, F.G.S., in illustration of his paper.

Fossil plants from the Kent Coalfield and lantern-slides, exhibited by E. A. Newell Arber, M.A., F.L.S., F.G.S., in illustration of his paper.

Sections of the South Wales Coalfield, by H. K. Jordan, F.G.S., presented by the South Wales Institute of Mining Engineers.

November 18th, 1908.

Prof. W. J. Sollas, LL.D., Sc.D., F.R.S., President, in the Chair.

The List of Donations to the Library was read.

The following communication was read:—

'On some Intrusive Rocks in the Neighbourhood of Eskdale (Cumberland).' By Arthur Richard Dwerryhouse, D.Sc., F.G.S.

Mr. T. V. Barker exhibited and described the method of using some of the 'universal instruments' devised by Prof. E. S. Fedoroff, of St. Petersburg. The exhibit included the universal stage, the graduated porcelain hemisphere (Prof. V. Nikitin), the stereographic rule, curved rule, crystal mirrors and globes, and various forms of graduated compensator. The determination of the optical constants, twin-law, and chemical composition of a plagioclase-twin was carried out, as an illustration of the special advantages of the universal stage.

In addition to the exhibits described above, rock-specimens and lantern-slides were exhibited by Dr. A. R. Dwerryhouse, F.G.S., in illustration of his paper.

December 2nd, 1908.

Prof. W. J. Sollas, LL.D., Sc.D., F.R.S., President, in the Chair.

James Mackintosh Bell, M.A., Ph.D., Director of the New Zealand Geological Survey, Wellington (N.Z.); George Washington Cobbe, 55 Kimberley Avenue, Seven Kings (Essex); Emiliano de la Cruz y Diaz, M.Inst.M.E., Ribas (Prov. of Gerona), and 88 Calle Balmes, Barcelona, Spain; Leonard V. Dalton, B.Sc. Lond., 10 Dewhurst Road, West Kensington, W.; Herbert James Davies, Geologist on the Geological Staff of the Burmah Oil Company Ltd., Yenangyoung (Upper Burma); Walter Hugh Davies, B.Sc., Science Master at Lewis's Secondary School, Pengam, 46 Maes-y-graig Street, Gilfach near Bargoed, *via* Cardiff; Charles Everitt, M.A., 67 Boston Avenue, Southend-on-Sea (Essex); William Storrs Fox, M.A., St. Anselm's, Bakewell (Derbyshire); Ernest Douglass Edward Isaacson, Mining Engineer, Pahiatua (New Zealand); Samuel Lister James, c/o Finlay, Fleming & Co., P.O. Box 181, Rangoon (Burma); Paul Legrand, 5 Rue Defacqz, Brussels (Belgium); Vernon Freeman Marsters, Cuerpo de Ingenieros de Minas del Perú, Lima (Peru); Francis Edward Norris, Hill View, Ryde's Hill, Guildford (Surrey); Albert Homer Purdue, M.A., F.G.S.A., Professor of Geology in the State University of Arkansas, & State Geologist of Arkansas, Fayetteville (Ark.), U.S.A.; Ajit Mohan Sen, B.Sc., Mining Engineer, c/o Messrs. Thomas Cook & Son, Ludgate Circus, E.C.; Ernst Sommerfeldt, Ph.D., Professor of Mineralogy in the University of Tübingen (Germany); and Leslie Alfred Edward Swinney, Assoc.R.S.M., Mining Engineer, Compañia Minera Poderosa de Collahuasi, Antofagasta (Chile), were elected Fellows of the Society.

The List of Donations to the Library was read.

The President announced that Fellows were invited to send in to the Secretary, so as to reach him not later than January 11th, 1909, the names of any Fellow or Fellows whom they might desire to see placed on the Council. All names so sent in would be carefully considered by the Council, in making their recommendations to the Fellows at the Annual General Meeting.

The President also announced that a Special General Meeting would be held on Wednesday, February 10th, 1909, in order to consider the result of the vote of the Fellows on the question of the Admission of Women into the Society.

The following communication was read:—

'The Geological Interpretation of the Earth-Movements associated with the Californian Earthquake of April 18th, 1906.' By Richard Dixon Oldham, F.G.S.

Mr. W. WHITAKER called attention to specimens of impressions of salt-crystals from a local sandstone in the Keuper Marl at North Curry (Somerset). Pseudomorphs of salt-crystals were well known; but, so far as he knew, the occurrence of impressions, not filled in (which might be taken as arrested pseudomorphs), had not been hitherto recorded in this country. The only notice of such that he knew of was from America, in 1842. Now that this occurrence was recorded, probably other examples would be noticed.

In addition to the above-mentioned specimens, the following maps, etc. were exhibited :—

Geological Survey of England & Wales: 1-inch map, new series, Sheet 254, 1908. Presented by the Director of H.M. Geological Survey.

Geologische Karte der Œsterreichisch-Ungarischen Monarchie, S.W. Gruppe, Nos. 78, 112, 113, & 118. 1908. Presented by the Director of the K.-k. Geologische Reichsanstalt.

Model of earthquake-movements, and lantern-slides, exhibited by R. D. Oldham, F.G.S., in illustration of his paper.

December 16th, 1908.

Prof. W. J. SOLLAS, LL.D., Sc.D., F.R.S., President, in the Chair.

Arthur Lewis, B.A. (Lond.), Wall Green, Padiham; Edwin Russell Lloyd, B.A., 7 Plantation Road, Oxford; Marmaduke Odling, B.A., 15 Norham Gardens, Oxford; and David Smith Palk, District Engineer in the Public Works Department of the Gold Coast Colony, Etwelle, Poole (Dorset), were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communication was read :—

'On the Igneous and Associated Sedimentary Rocks of the Tourmakeady District (County Mayo).' By Charles Irving Gardiner, M.A., F.G.S., and Prof. Sidney Hugh Reynolds, M.A., F.G.S. With a Palæontological Appendix by Frederick Richard Cowper Reed, M.A., F.G.S.

The following specimens, drawings, and maps were exhibited :—

Specimens, microscope-sections, and lantern-slides, exhibited by C. I. Gardiner, M.A., F.G.S., and Prof. S. H. Reynolds, M.A., F.G.S., in illustration of their paper.

Four water-colour drawings of the Hawaiian Volcanoes, painted and presented by Arthur Brown, Esq., F.G.S.

Folios 151–159 of the United States Geologic Atlas, 1907–1908, presented by the Director of the United States Geological Survey.

January 13th, 1909.

Prof. W. J. Sollas, LL.D., Sc.D., F.R.S., President, in the Chair.

Thomas Richard Henry Garrett, M.A., 16 Queensland Road, Boscombe, and Albert Tulip, B.Sc., Civil Engineer, Choppington, Morpeth, were elected Fellows; and Dr. Bundjirô Kôtô, of Tokyo, and Prof. Johan H. L. Vogt, of Christiania, were elected Foreign Members of the Society.

The following Fellows of the Society, nominated by the Council, were elected Auditors of the Society's Accounts for the preceding year: Dr. Aubrey Strahan, F.R.S., and James Vincent Elsden, B.Sc.

The List of Donations to the Library was read.

The President announced that the Council, at its meeting that afternoon, had passed the following resolution:—

'The Council of the Geological Society desires to express to the relatives of Prof. H. G. Seeley, F.R.S., its profound sorrow in the death of one who had been a Fellow for nearly half a century, had frequently served on the Council of the Society, and, for so many years, continued to enrich the literature of Geology and Palæontology by numerous original researches in these Sciences.'

The following communications were read:—

1. 'On Labradorite-Norite with Porphyritic Labradorite.' By Prof. Johan H. L. Vogt, F.M.G.S.

2. 'On the Genus *Loxonema*, with Descriptions of New Proterozoic Species.' By Mrs. Jane Longstaff (*née* Donald), F.L.S. (Communicated by Dr. G. B. Longstaff, M.A., F.G.S.)

The following specimens and lantern-slides were exhibited:—

Fossil gasteropods from various collections, exhibited in illustration of Mrs. Longstaff's paper.

Lantern-slides, prepared by Mr. Zealley and exhibited by Prof. W. W. Watts, F.R.S., Sec.G.S., in illustration of Prof. Johan H. L. Vogt's paper.

January 27th, 1909.

Prof. W. J. SOLLAS, LL.D., Sc.D., F.R.S., President,
in the Chair.

The List of Donations to the Library was read.

The following communications were read:—

1. 'The Conway Succession.' By Miss Gertrude L. Elles, D.Sc. (Communicated by Dr. J. E. Marr, F.R.S., F.G.S.)

2. 'The Depth and Succession of the Bovey Deposits.' By Alfred John Jukes-Browne, B.A., F.G.S.

The following specimens and maps were exhibited:—

Rock-specimens and fossils, exhibited in illustration of Miss Gertrude L. Elles's paper.

Geological Survey of England & Wales: 1-inch map, n.s., No. 126, Nottingham (Drift), colour-printed, 1908. Presented by the Director of H.M. Geological Survey.

February 10th, 1909.

Prof. W. J. SOLLAS, LL.D., Sc.D., F.R.S., President,
in the Chair.

John Thomas Audas, Deputy Commissioner, & Inspector of Mines, Eugowra, Town Hill, Pietermaritzburg (Natal); Gilmour Ewing Brown, Assoc.R.S.M., Mining Engineer, Applegarth, Balloch (Dumbartonshire); Ernest William Byrde, Assoc.R.S.M., Mining Engineer, 68 Kimbolton Road, Bedford; Frederick Feather, F.R.Met.Soc., Civil Engineer & Surveyor, Chepstow (Monmouthshire); Thomas Griffith Taylor, B.E., B.Sc. (Sydney), Emmanuel College, Cambridge; and Edmund Bessell Whalley, H.M. Inspector of Mines, 9 South Gray Street, Edinburgh, were elected Fellows of the Society.

Dr. CHARLES GILBERT CULLIS, F.G.S., having been nominated by the Council, was elected Auditor of the Society's Accounts for the preceding year, in place of Mr. J. V. Elsden, who had been prevented by illness from participating in the audit.

The List of Donations to the Library was read.

The PRESIDENT announced that the Council, at its meeting that afternoon, had passed the following resolution :—

'The Council of the Geological Society records its sense of the very great loss which the Society sustains from the death of Mr. W. H. HUDLESTON, F.R.S. By his distinguished services as President and as Secretary, by the constant interest which he took in the Society's affairs, and by the distinction of his high scientific reputation, he had laid the Society under a deep obligation. The Council desires to express to Mrs. Hudleston the sincere sympathy of the Society in her bereavement.'

The following communications were read :—

1. 'Note on some Geological Features observable at the Carpalla China-Clay Pit in the Parish of St. Stephen's (Cornwall).' By Joseph Henry Collins, F.G.S.

2. 'Some Recent Observations on the Brighton Cliff-Formation.' By Edward Alfred Martin, F.G.S.

The following specimens, photographs, and map were exhibited :—

Specimens and photograph, exhibited by J. H. Collins, F.G.S., in illustration of his paper; also two photographs of the Central Trevisco Mine.

Septarian nodules encrusted with selenite, from the London Clay, Swanscombe Park (Kent), exhibited by W. Whitaker, B.A., F.R.S., F.G.S.

Geological Survey of Scotland: 1-inch map, Sheet 45, Oban (Solid), hand-coloured, 1907. Presented by the Director of H.M. Geological Survey.

At a Special General Meeting held at 7.45 P.M., before the Ordinary Meeting, the following resolution was proposed by Dr. A. SMITH WOODWARD, F.R.S., and seconded by Dr. R. D. ROBERTS:

'That it is desirable, under the existing Charter, to admit Women to candidature for the Fellowship of the Society, on the same terms as men.'

A ballot having been asked for, the resolution was rejected by 50 votes to 40.

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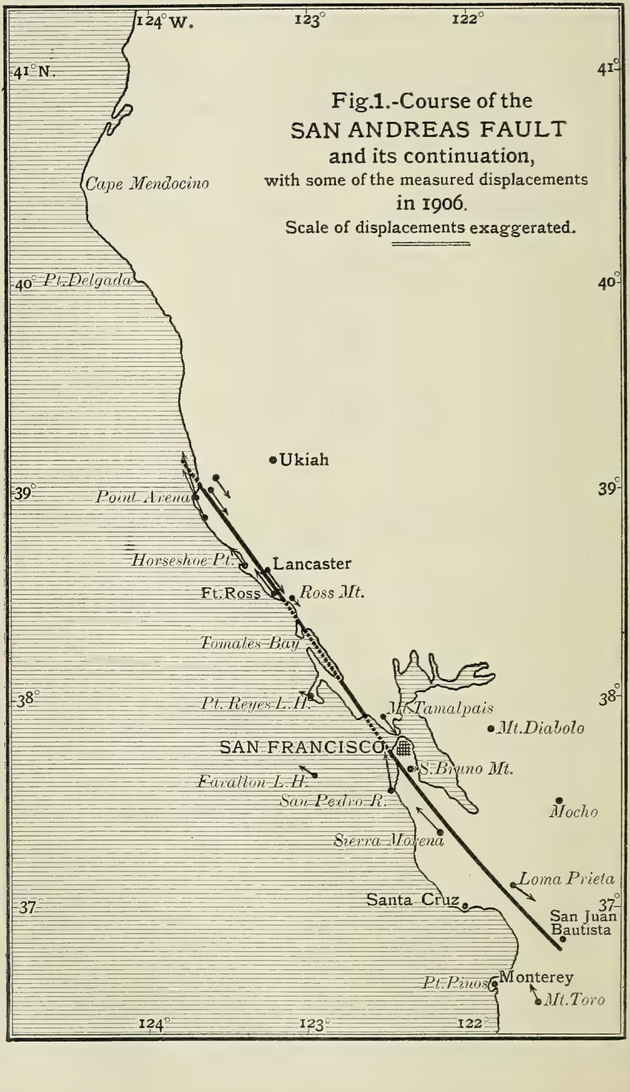
1. *The* Geological Interpretation *of the* Earth-Movements *associated with the* Californian Earthquake *of April 18th, 1906.* By Richard Dixon Oldham, F.G.S. (Read December 2nd, 1908.)

The Californian earthquake of 1906 was accompanied by very considerable displacements of the ground along a great fault-line, which has been traced for a distance of about 200 miles from its southern extremity to the point where it finally passes out under the sea. As several stations of the principal triangulation lay within the disturbed area, the Government of the United States decided to repeat the observations over this area, and determine with accuracy the present positions of the points previously fixed. The result of this work has been issued, with most commendable promptness, as an Appendix[1] to the Report of the Coast & Geodetic Survey for 1907, and the results seem of such importance, from the light thrown on the nature of the earth-movements which gave rise to this earthquake, that I have thought it desirable to make a detailed study of them from the geological point of view.

The area covered by the observations is not co-extensive with, but covers the most important part of, the seismic area; it extends from near Monterey, in the south, to Point Arena, in the north, and within this area all the points fixed by the triangulation which was carried out at various times between 1851 and 1899 were again fixed after the earthquake of 1906.

When the results came to be worked out, it was found that wherever triangulation of earlier date than about 1868 was connected up with triangulation of later date, the positions of the

[1] 'The Earth-Movements in the Californian Earthquake of 1906' by John F. Hayford, Inspector of Geodetic Work, & A. L. Baldwin, Computer, Coast & Geodetic Survey. Washington, 1908. [Reprinted in the Report of the State Earthquake Investigation Commission. Carnegie Institution, Washington, 1908.]


124° W.
123°
122°
41° N.
41°
Fig.1.-Course of the
SAN ANDREAS FAULT
and its continuation,
with some of the measured displacements
in 1906.
Scale of displacements exaggerated.
Cape Mendocino
40°
Pt. Delgada
40°
Ukiah
39°
Point Arena
39°
Horseshoe Pt.
Lancaster
Ft. Ross
Ross Mt.
Tomales Bay
38°
Pt. Reyes L.H.
Mt. Tamalpais
38°
Mt. Diabolo
SAN FRANCISCO
S. Bruno Mt.
Farallon L.H.
San Pedro R.
Mocho
Sierra Morena
Loma Prieta
37°
Santa Cruz
37°
San Juan
Bautista
Pt. Pinos
Monterey
Mt. Toro
124°
123°
122°

connecting points did not agree. Originally the differences were adjusted as errors of observations, but in Messrs. Hayford & Baldwin's report the more reasonable conclusion is adopted that the discrepancies are to be attributed to displacements connected with[1] the earthquake of 1868.

As a consequence of this latest elaborate discussion of the data, the numerous stations dealt with fall into three classes: first, those of which the shiftings in 1868 and in 1906 are both known and can be separated from each other; secondly, those in which the latter but not the former are determinable; and thirdly, those in which the total displacement connected with the earthquakes of 1868 and 1906 is known, but not how much was due to each separately.

In the Report the displacement of several stations in the third class is split up, that produced in 1868 being inferred from the known displacements of other stations in the same region; the method is of doubtful validity, and I have thought it safer to exclude the inferred displacements from consideration.[2] With this omission, the data available for discussion are given in the tabular statement appended to this paper (p. 15), in which the stations are re-arranged, from the original list, in their order of occurrence along the fault-line from south to north. The displacements attributed to 1868, and the total displacements, where those of 1906 were not separately determined by direct observation, are also given, but will only be referred to incidentally, attention being devoted primarily to the movements of 1906.

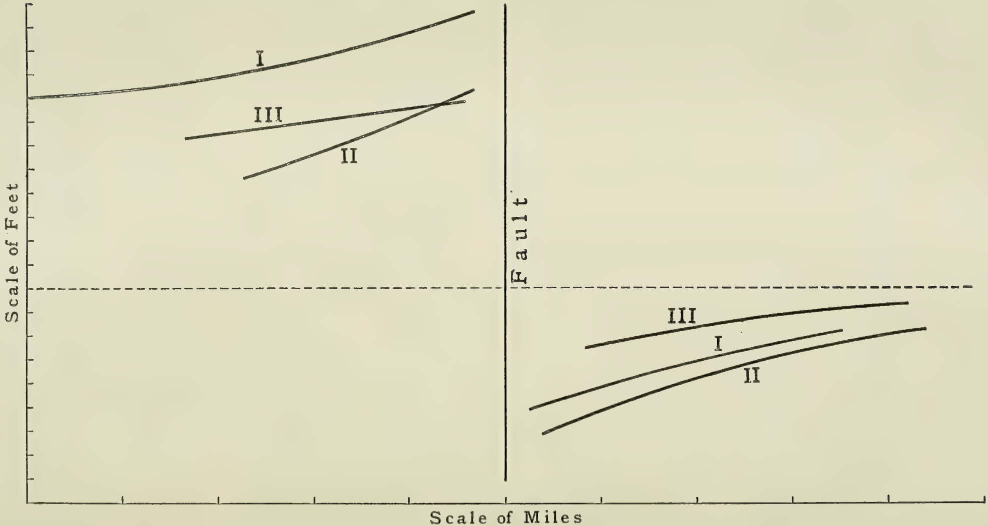
One more explanation is necessary. In the original report many of the displacements are classed as doubtful; generally, this means that the calculated displacement is so small, that it may fall within the limits of errors of observation, but in a few cases the doubt arises from the fact that either the number or the character of the observations is not such as affords a satisfactory check. I have included and used all those falling within the former category, as the fact that one station moved very little, if at all, may be as important as that another was displaced a considerable distance; but have excluded from the discussion all those of the second category, which are distinguished by a mark of interrogation in the tabular statement.

§ 2. Turning now to the discussion of the data, we may deal with the displacements in two distinct ways: either considering the calculated absolute displacements, or looking merely to the relative displacements as between neighbouring stations. The determination of the former of these depends on the assumption

[1] I use the words connected with, as it is by no means certain that they took place at the time of the earthquake, although they may reasonably be regarded as the result of the same cause as that which gave rise to the earthquake. In 1906, movements near the fault-line certainly occurred at the time of the earthquake; but the measured displacements of the trigonometrical stations may partly have preceded and partly have followed the earthquake.

[2] The inclusion of these data would not in any way invalidate, but rather support, the conclusions arrived at farther on; the support, nevertheless, would be more apparent than real.

Fig. 2.—*Diagram of displacements along the San Andreas fault.*



[A straight line, represented by the broken line, crossing the fault-line at right angles before the earthquake, was displaced to the positions marked by the heavy curved lines in the neighbourhood of Point Arena (I), Fort Ross (II), and south of San Francisco (III).]

that the base from which the triangulation started was unaltered by the earthquake; the latter is independent of it, for no conceivably permissible alteration in the length of the base would make any material change in the apparent relative movement of neighbouring stations. I shall therefore deal first with this, and especially with the movement of points near the fault-line.

At the extreme south, a number of stations lying west of the fault have been displaced south-eastwards by the combined effects of the movements of 1868 and 1906, and it is probable that part of this movement took place in connexion with the 1906 disturbance. The conditions in this region are, however, somewhat different from those farther north: for here the fault-line trends eastwards from its general course, and movement dies out as a surface-phenomenon. If, for the present, we exclude these stations from consideration, three facts stand out: (1) that all stations to the east have moved south-eastwards, and all to the west have moved north-westwards; (2) that the south-easterly shifting was less than the north-westerly; and (3) that stations near the fault-line have moved farther than those more remote.

These facts are noticed in Messrs. Hayford & Baldwin's report: according to their figures, the average displacement at 0·9 mile from the fault-line on the eastern side was 5·1 feet, at 2·6 miles 2·8 feet, and at 4 miles 1·9 feet; on the west side the figures are, at 1·2 miles 9·7 feet, at 3·6 miles 7·8 feet. As a number of stations were utilized in obtaining these averages, at which the displacement attributed to the 1906 earthquake was deduced by inference, it will be desirable to examine the evidence yielded by those stations at which the 1906 displacements were directly determined. These form three natural groups: the first consists of 7 stations near and to the south of San Francisco, the second of 13 stations near Fort Ross, and the third of 9 stations in the Point Arena neighbourhood. Subdividing each of these groups according to direction from the fault and again according to distance, we get the following result for stations at a distance of 5 miles or less from the fault-line:—

TABULAR STATEMENT *showing the average displacements of stations within 5 miles of the fault.*

	Under 2·1 miles.			2·1 to 5 miles.		
	No. of Stations.	Mean Distance.	Mean Shift.	No. of Stations.	Mean Distance.	Mean Shift.
W. side of fault:		miles	feet		miles	feet
San Francisco group.	2	0·9	7·9	2	3·5	7·5
Fort Ross group	7	1·3	6·9			
Point Arena group ...	1	0·9	10·7	5	4·1	8·5
E. side of fault:						
San Francisco group.	1	1·6	1·3	2	3·7	0·7
Fort Ross group	5	1·1	4·7	1	4·3	1·8
Point Arena group ...	2	0·2	5·0	1	2·4	2·6

From these figures it will be seen that the statements in Messrs. Hayford & Baldwin's report as to the greater movement near the fault are borne out, although the figures are slightly different; excluding the stations on the west side of the fault in the San Francisco group, the displacement in the outer zone is from 20 to 60 per cent. less than in the inner, and the decrease is more rapid on the eastern than on the western side. Moreover, these displacements are positive; that is to say, the stations near the fault have not lagged behind, but have moved forward in opposite directions to a greater distance than those farther away.

The increase of displacement was not, apparently, carried right up to the fault-line, and the shifting along this seems to have been less than the relative displacement of points at a little distance from the fault. The published data do not admit of any direct comparison, as we do not possess a series of measurements at points situated along or near to a straight line at right-angles to the run of the fault; but the displacements at the fault-line, as measured by the offset of interrupted fences and roads, seem to have been no greater, and sometimes less, than those at a distance of a mile or so away.[1]

The diminished displacement at the fault-line is not difficult to explain, and may reasonably be ascribed to a frictional drag or resistance to movement along this plane. The increase in displacement as the fault is neared, and until it is actually reached, is not so easy to explain; but, before dealing with this point, it will be well to see how far from the fault-line permanent displacements can be recognized, and to determine the area which has suffered permanent distortion in connexion with the earthquake.

In the Report it is assumed that the stations Mocho and Mount Diabolo had suffered no displacements, and that the line joining them could be accepted as a base-line of the triangulation in 1906–07, being unaltered in length or direction. The observations show that there has been no appreciable change in the azimuth of the line joining these two stations, and the authors have most conclusively shown that the apparent displacement of other stations cannot be explained by any alteration in its length; but they have not shown that there was no change in the length of the accepted base-line, and it is necessary to consider whether the displacement of stations, which certainly took place in connexion with this earthquake, may not have affected the assumed unaltered base.

In 1897, after the great earthquake in Assam, a part of the primary triangulation in the disturbed area was reobserved, and the result, as published by the Great Trigonometrical Survey, indicated an apparent enlargement of the area resurveyed. In this case, it was possible to show that the line which was taken as an unaltered

[1] [The Report of the State Earthquake Investigation Commission, received since this paper was read, shows that this was confined to the immediate neighbourhood of the fault-line. Fig. 15 on p. 64, fig. 21 on p. 71, and fig. 38 on p. 101 are plans of dislocated fences which show clearly a drag or diminished displacement within 120 feet or less of the dislocation.]

base-line, because it reduced the apparent displacements to a minimum, had very probably been shortened[1]; and as this shortening would have the effect of increasing the scale of the survey, and of making the more distant stations appear to be farther removed from each other and from the base-line, it became evident that the calculated displacements were in all probability made up of two elements, (1) the real shift due to the earthquake, and (2) an apparent shift due to an alteration in length of the base-line. It was not, however, possible to determine the separate amounts due to each of these causes.

On examining the chart of displacements in California, the same feature is evident as that which was observed in Assam; that is to say, there is, in spite of irregularities and exceptions, a general tendency to displacement outwards, or away from the base-line, which suggests that this had been shortened. For instance, Point Pinos, at the southern limit of the area, has been shifted about 16 or 19 feet to south-east by east; Bodega Head, near the northern limit, has been shifted about 17 feet to north by west, as the combined result of the earth-movements in 1868 and 1906. A large part of these apparent displacements could be explained, on the supposition that the base-line has been shortened by about 8 feet; but it is not suggested that shortening to this extent has taken place, for a consideration of the apparent displacements of other stations shows that the alteration, if any, must have been considerably less than this.

For the 1906 earthquake the data are, unfortunately, scanty near the limits of the area, and the only real check which can be applied is the displacement of Farallon lighthouse by 5·8 feet to north 62° west, or at an angle of about 27° with the general direction of the fault-line. A shortening of the assumed unaltered base-line would give rise to an apparent westerly displacement of Farallon by about double as much as the shortening of the base-line: if, then, the whole of the westerly displacement of Farallon is apparent, it involves a shortening of the base-line by about 1·3 feet; and, if the real displacement of Farallon was parallel to the fault-line, it leaves an apparent westerly displacement of 1·8 feet to be explained by a contraction of ·9 foot in the length of the base-line. We may, therefore, conclude that any alteration which took place in the distance between Mocho and Mount Diabolo must have been of the

[1] Obsessed by the knowledge that the earth is losing heat by radiation into space, and the deduction, by no means inevitable, that it is therefore contracting, geologists have been too prone to regard all strains in the crust of the earth as necessarily compressional, and to ignore the possibility that large areas may possibly be subject to tensile strains. In the case of the Assam earthquake the hypothesis of origin, which seemed most probable to me, almost necessitated a shortening of the line taken by the Trigonometrical Survey as an unaltered base; but, if Col. Harboe's suggestion ('Beiträge z. Geophysik' vol. v, 1903, pp. 206–36) be accepted, this necessity disappears, and the expansion of the area resurveyed may be real. In California, there seems no escape from the conclusion that there has been a lengthening of the coast-line; the width of the opening of Monterey Bay has increased 10 feet and the length of the Bay of San Francisco by about the same amount, as the combined result of the movements connected with the earthquakes of 1868 and 1906.

nature of compression, and could not have exceeded 1 foot at most. This measure must be accepted as a maximum value; and although we may be certain that the base-line was not shortened by more than a foot or so, it is by no means certain that it was altered to this extent, and it is evident that the base-line was either outside, or not far from, the eastern limit of the permanently distorted area.[1]

To the westwards, it is impossible to say how far this extended under the bed of the sea; Farallon lighthouse, at 23 miles from the fault, was certainly included, for the northerly displacement cannot be explained by any shortening of the base-line, and the fact that the displacements near the fault-line were greater on the west than on the east suggests that the permanently distorted area extended farther to the west than to the east of the fault-line. The width of the area over which displacement of the ground took place to a greater or less extent may be put, roughly, as not far from 30 miles to the east and 50 miles to the west, or a total width of about 80 miles, near the parallel of San Francisco.

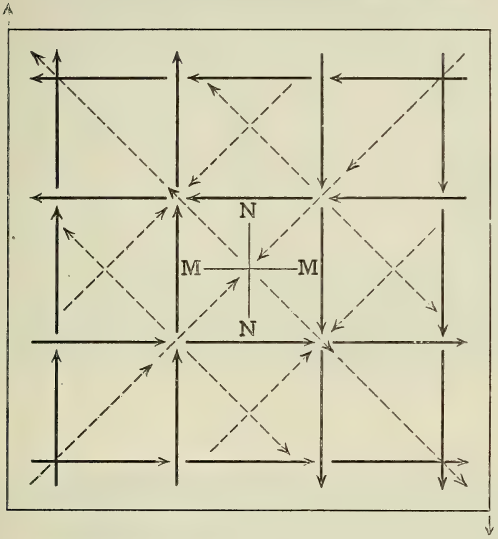
§ 3. We may now turn to the interpretation of the displacements, and are met at the outset by the apparently inexplicable nature of the movements near the fault-line, movements which appear to involve thrusts in opposite directions at the same time and the same place. An explanation has been suggested to me by Prof. Perry, which accounts for most of the facts. If a block of coherent material is subjected to a lateral distortion as indicated by the arrows outside the square in fig. 3 (p. 9), it will experience a series of stresses and strains represented by the arrows inside the square; here we have a right-handed couple, indicated by the vertical unbroken arrows, balanced by a left-hand couple, indicated by the horizontal arrows, and as the resultant of these two couples the system of compressional and tensile stresses indicated by the broken arrows. These compressional and tensile stresses, in combination with each other, produce a shear in the directions MM and NN; and, if there be weakness in either of these directions, a sliding fracture may arise, accompanied by movements on opposite sides in the directions of the unbroken arrows, while elsewhere, if there is not weakness, or the stresses are not great enough to cause fracture, there will be a strain but no movement, and so we have an effect produced which resembles the shifting at the San Andreas fault.[2]

[1] [The distribution of isoseismals, as determined by the Californian Earthquake Investigation Commission, shows that this, and the statements in the subsequent paragraph, are only true so far as they apply to displacements directly connected with the movement along the San Andreas fault. There was evidently another centre of disturbance in the San Joaquin Valley, about 40 miles east by south of Mocho and about 20 miles beyond the continuation of the Mocho-Mount Diabolo line.]

[2] To prevent misunderstanding, it may be well to state that I use the words strain, stress, and shear in their physical sense. Strain was defined by Rankine as the change of volume and figure, constituting the deviation of a molecule of a solid from that condition which it preserves when free from the action

Now, it must be borne in mind that the apparently complicated series of stresses just described is in reality a complete system of which no member can exist alone, and the production of any one of the four, by application of an external force, brings the other three

Fig. 3.—*Diagram showing couples and shearing stresses.*



into play; consequently, it is easy to construct a model which will illustrate the effect. The form that I have adopted consists of a block of indiarubber 8 inches long by 4 inches broad, with a slit 4 inches in length cut longitudinally in its centre; this, as represented in figs. 4 & 5 (p. 10), is enclosed in a loose-jointed wooden

of external forces, and stress as the force or combination of forces which such a molecule exerts in tending to recover its free condition. Lord Kelvin introduced the use of the term stress for the external forces or system of forces by which the deformation is produced; this is equal, but opposite in direction, to the force involved in Rankine's definition, and, being usually more convenient in practice, has come to supersede it. Shear is a strain consisting of a compression in one direction, and an elongation, in the same ratio, in a direction perpendicular to the first. Strain in its popular sense involves a partial rupture of continuity, and results when the strain, in its physical sense, overcomes the molecular cohesion of the substance strained. It is somewhat unfortunate that there should be these two meanings for the same word, as they are in reality contradictory; the production of a strain in the popular sense is in fact a relief of strain in the physical sense of the word.

Figs. 4 & 5.—*Two views of a model constructed to illustrate the displacements caused by the Californian earthquake of April 18th, 1906.*

Fig. 4.

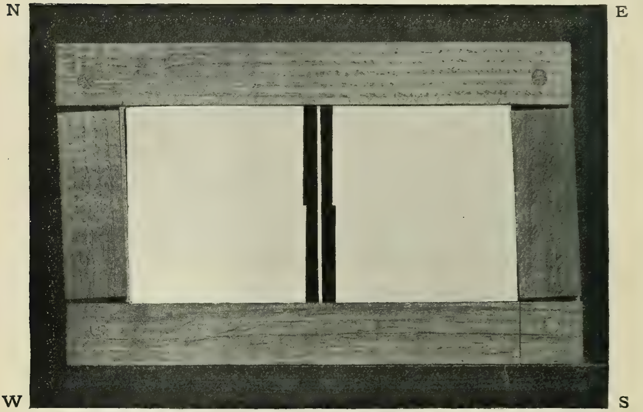
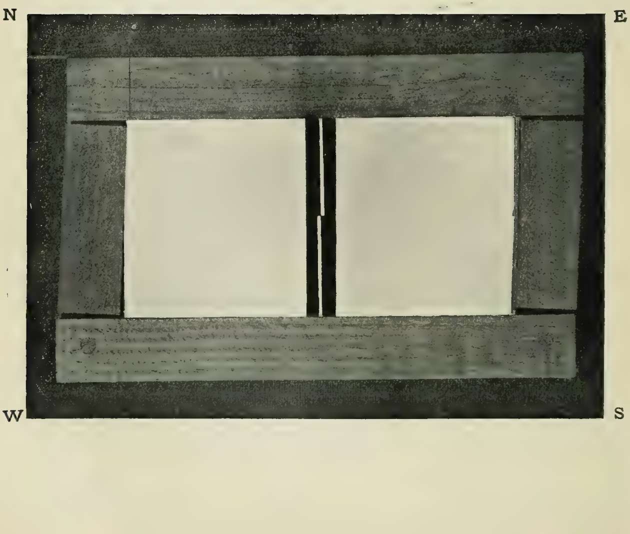


Fig. 5.



frame, fitting closely but without adhesion, and capable of distortion out of the square for the purpose of causing compression along one diagonal, while the concomitant lengthening of the other diagonal allows room for expansion of the indiarubber block. In the position represented by fig. 4 the frame is slightly distorted so as to produce compression along the diagonal E–W, the block being free to expand along the diagonal N–S, as shown by the gaps at these corners between the block and the frame; and in this view may be seen a narrow white band, extending in a straight line across the block between the centres of the two longer sides of the block. On either side of the narrow white band is a broader black band, the purpose of which will become apparent in fig. 5; in fig. 4 it is broken at the slit, the upper half being shifted to the left and the lower to the right. Fig. 5 represents the block in another condition, compressed along the diagonal N–S, and free to expand along E–W. The black band, which was broken at the slit in fig. 4, now forms a continuous band across the block, while the white line in the middle of it has become broken. There was no appreciable movement of the outer ends of these bands as between the two extreme positions, so that the edges of the black and white bands, when continuous, represent straight lines joining two stationary points, on either side of and at a distance from the slit, and a comparison of the two views illustrates the manner in which the application of shearing stresses to the block as a whole can produce positive displacements in opposite directions along a line of weakness. A comparison of the two figures shows that, as a result of the alteration of shape from that represented in fig. 4 to fig. 5, the upper half has moved to the right and the lower to the left, the amount of displacement increasing progressively as the slit is approached, and this is just what took place along the San Andreas fault-line in California.

We have, then, an explanation and an illustration of the displacements connected with the earthquake of 1906. Neither explanation nor illustration is complete in every respect, but they indicate the kind of strain which preceded and gave rise to the earthquake; they explain the occurrence of detached areas of increased violence of shock by the formation or movement of independent fissures; and finally they show that this fault was not, as has been generally thought, the cause, but a consequence, of the earthquake, if the word be used in its fullest sense as covering the whole of the disturbance.[1]

[1] [In 'Nature,' May 28th, 1908 (vol. lxxviii, p. 78), I pointed out that two distinct forms of disturbance are covered by the ordinary use of the word earthquake, namely—(1) the vibratory movement, of the nature of an elastic wave, which is due to molecular disturbance, and leaves the ground as it was before the earthquake, apart from damage to buildings or disturbance of the surface-layers which may be produced as a secondary result of the molecular displacements involved in the propagation of the wave-motion; and (2) molar displacements of solid rock, which are not the result of the wave-motion, and are permanent in the sense that the masses affected do not return to their original position after the earthquake has passed. I proposed that the word earthquake should be limited to the first sense, and that the word earthshake should be

§ 4. This conclusion, so much at variance with ideas prevalent at the present time, necessitates a brief examination of the history of our knowledge of the connexion between faults and earthquakes.

The earliest published description of the appearance of faulting at the surface of the earth at the time of an earthquake, contemporaneously recognized as such, appears to be in the account, compiled by Sir Charles Lyell from the narratives of eye-witnesses, of the New Zealand earthquake of January 23rd, 1855 [1]; but in this, and for some time subsequently, the fault-movement was regarded as a consequence, not the cause, of the earthquake. The nature of an earthquake was inaccurately appreciated—it might almost be said, was wholly misunderstood—before the publication of that remarkable series of researches by which Robert Mallet established seismology as a science; to him, an earthquake was a wave or series of waves of elastic compression, propagated outwards from a focus or origin of small size relative to the area over which the shock was felt. A disturbance of this character could not produce fissures in solid rock, but the connexion of earthquakes with faults and fractures was recognized and regarded as that of effect to cause; and when the Mino-Owari earthquake of October 28th, 1891, was found to have been accompanied by the production at the surface of a fault more than 60 miles long, with a throw of 20 feet in places, it seemed obvious that here was a sufficient cause for the phenomena which accompanied it. Moreover, the knowledge that regions where earthquakes are most frequent are also regions of great and recent tectonic changes, gave rise to a habit of connecting earthquakes with the production of the great structural features, more especially with the great faults or flexures which can be recognized by surface-observations. The Assam earthquake of 1897 was associated by Mr. La Touche [2] with the great monoclinal flexure along the southern edge of the Assam range; and in 1906 the San Francisco earthquake was immediately ascribed, by more than one authority, to fresh movement along the San Andreas fault.[3] In the former case, the prophecy was not borne out by subsequent investigation; in the latter case, it received an apparent fulfilment, which loses value with a fuller consideration of the facts known in regard to this and other earthquakes.

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used for the second. Exception has been taken to this proposal; and, on consideration, I admit the inconvenience which might arise from an attempt to limit the meaning of the word e a r t h q u a k e, which I use in its ordinary sense and take to include all the phenomena concerned. There seems to be, however, a real need for special terms to be used when it is necessary to distinguish between these two forms of earthquake-disturbance: for the molar displacements I propose to adapt the verb μοχλέυω, I heave or displace, which, being only used for the displacement of heavy weights or masses, appears appropriate in this connexion, and from it we obtain m o c h l e u s i s for the result, and, less legitimately but conveniently, m o c h l e u s e i s m for the disturbance by which it is produced. Similarly, for the vibratory movement I suggest o r c h e s i s and o r c h e s e i s m, from the verb ὀρχέομαι, I dance or tremble.]

[1] Bull. Soc. Géol. France, ser. 2, vol. xiii (1856) p. 661, and 'Principles' 10th ed. vol. ii (1868) Chap. xxviii.

[2] 'Nature,' vol. lvi (1897) p. 444.

[3] 'Popular Science Monthly' August 1906, p. 104.

The growth of our knowledge of earthquakes is making it continuously more and more evident that, whether great or small, they have little or no connexion with the faults which reach the surface of the earth. Leaving out of account minor earthquakes, the origin of which can seldom be determined with sufficient accuracy to connect them, even by position, with—though they can frequently be shown to be independent of—any known surface-faults, and considering only great earthquakes, we have Col. Harboe's demonstration that the origin of the Mino-Owari earthquake was probably much more extensive and complicated than the fault to which it is commonly ascribed, and the certainty that the Assam earthquake was neither solely nor mainly the result of movement along the great structural flexure which separates the elevated area of the Assam Hills from the depressed area of the Barak Valley. The Kangra earthquake of 1905 was unaccompanied by any surface-faulting, or conspicuous changes of surface-level, nor does its origin seem to have been due to movement along the great boundary-fault of the Himalayas. The Californian earthquake of 1868 was unaccompanied by any surface-faulting, and, so far as can be judged from the displacements of trigonometrical stations, was the result of a set of strains very different from that of 1906, and this again was evidently far from being localized in its origin to the displacements along the San Andreas fault. The local centre of great violence at Santa Rosa points to movement along an independent fracture or fault, and the same may be said of the earthquake at Cape Mendocino, which can only be attributed to a submarine extension of the San Andreas fault by postulating an improbable change in the direction of the course of that fault.

Not only are the irregularities in distribution, both of the violence of the shock and of the permanent displacements, inexplicable if the origin of the earthquake is assumed to have been localized to a single fissure; but they are also difficult, if not impossible, to account for if we suppose the earth's crust to have been involved as a unity in the strains which caused the earthquake. This difficulty very largely disappears if we adopt the not improbable hypothesis that the outer 30 miles or so of rocks (which we are in the habit of designating the crust of the earth) includes an outer skin of a few—probably very few—miles in thickness of more discontinuous and fractured rock.

It is not to be supposed that there is a hard and fast boundary between the rocks constituting what I have called the outer skin, and those forming the greater part of the thickness of the crust. To some extent there must be a difference of composition, for the former consists largely of clastic rocks, composed of the products of weathering and denudation, while the latter is mainly composed of matter which has not been exposed to the action of air and water at the surface of the earth. A more material difference, however, is to be looked for in the fact that the surface-rocks, being exposed to a smaller pressure, still preserve in the main the characteristics that we attach to solidity; while at a greater depth the increase of pressure causes matter, which must still be called solid, to take on the

power of changing its form without breach of continuity, which we speak of as flow and regard as the most conspicuous characteristic of a fluid.

It is to the outer skin that we must look for the origin of the greater part of the disturbances which we call earthquakes, and usually to a sudden yielding, ordinarily of the nature of fracture, to strains set up in it. Probably all local earthquakes originate in the outer skin; the strains may owe their origin to slow movements of the underlying crust, but the abrupt yielding and sudden displacements do not descend into it, and such earthquakes, though occasionally of great violence near their origin, are characterized by their localization and produce no impression on the most delicate instruments at small distances outside the seismic area.

In the case of great earthquakes, like the Californian one of 1906, the surface-disturbance is still the immediate result of fracture and yielding of the outer skin, but these are the result and accompaniment of an abrupt yielding of the underlying crust. It is difficult to believe that this yielding can be precisely similar to the fractures which may be and are produced in the surface-rocks; but it is probably analogous in the sense that the ultimate result is the same, and that there is a sudden yielding and displacement of adjoining masses of matter relative to each other. On this hypothesis we have, in great earthquakes, two closely connected and yet distinct disturbances: there is first the dislocation of the outer skin, which gives rise to the surface-shock, and secondly the deep-seated displacement, or bathyseism, which gives rise to the wave-motion, which, propagated to great distances, impresses itself on suitable instruments all over the world and constitutes the teleseism, or world-shaking earthquake.

It is possible that the downward continuation of the San Andreas fault may pass deep into or even right through the crust of the earth, and have given rise to the deficiency in power of resistance which resulted in a sudden yielding under strain and so produced the Californian earthquake of 1906, but this is by no means necessary. The distribution and variation in amount and direction of the surface-displacements suggest that the yielding of the inner crust followed more or less closely the run of the coastline, and that the strains in the outer skin were, consequently, greater along this zone than elsewhere; but there is no necessity, either in this zone or farther away, for an exact coincidence between the surface-displacements (which must have been influenced, to a large extent, in direction and amount by local irregularities in the power of resistance of the superficial rocks) and the movements which affected the crust as a whole.[1]

[1] [In the description of the surface-displacements, contained in the Report of the State Earthquake Investigation Commission, it is shown that where the outcrop of the San Andreas fault is covered by alluvium, it frequently manifests itself as a series of fractures arranged in échelon and each individually running obliquely to the general direction of the main fault. According to the view developed in the paper, the relation of the displacements in the bathyseism to the San Andreas fault is very similar to that of the displacements along the fault to the obliquely disposed surface-fractures.]

The San Francisco earthquake of 1906 is being subjected to an investigation more complete and exhaustive than any great earthquake has yet received; the report, when completed, will be a document of the greatest importance, and, until it lays all the details before us, any attempt to follow up the subject would be futile: yet this much is evident, that the great fault was not the sole, nor even the principal, cause of the earthquake, and that the movement along it was merely an incident in the final rupture, consequent on the growth of a widespread strain, distributed over an area of the earth's crust comparable in magnitude with, and possibly equalling or exceeding in size, the seismic area. This strain was of the nature of a shear, such as might be produced by a shifting more or less parallel with the coast-line, with compression in a direction about north and south and extension in a direction about east and west. How it was produced cannot be established, and more than one hypothesis is tenable; but, however produced, one thing is clear, that the forces concerned must have been very different from those which led to the formation of the San Andreas fault. The earthquake, therefore, cannot be regarded as an incident in the growth of the fault, nor the fault as the cause of the earthquake.

Appendix.

List of Displacements *associated with the Californian earthquakes of* 1868 *and* 1906, *as determined by the U.S. Coast & Geodetic Survey in* 1906–07.

Station.	Position relative to Fault.		Displacements.						
			1868.		1906.		Combined.		
	mi.	dir.	ft.	dir.	ft.	dir.	ft.	dir.	
Mount Toro	20	W.	...	......	3·1	N. 12° W.			
Gavilan	4·0	W.	...	......	...	......	17·1	S. 51° E.	
Point Pinos Station	24	W.	...	......	...	......	16·1	S. 33° E.	
Point Pinos Lighthouse	24	W.	...	......	...	......	19·3	S. 37° E.	
Santa Cruz Lighthouse	12	W.	...	......	2·0	N. 37° W.	...	......	?
Santa Cruz Az. Station	12	W.	...	......	...	......	8·3	S. 15° E.	
Loma Prieta	3·0	E.	9·9	S. 53° E.	3·2	S. 57° E.	13·1	S. 54° E.	
Lick Observatory	22	E.	...	......	0·4	E.			
Black Mountain	0·9	E.	...	......	...	......	6·9	S. 44° E.	
Pulgas E. Base	7·0	E.	...	......	...	......	1·3	S. 58° E.	
Sierra Morena	2·7	W.	...	......	5·5	N. 44° W.			
Red Hill	12	E.	2·1	N. 52° E.	1·0	N. 35° E.	3·1	N. 47° E.	
Pulgas W. Base	2·2	E.	...	......	...	......	2·4	S. 16° E.	
Guano Island	6·0	E.	...	......	...	......	0·7	S. 28° W.	
Montara Mountain Peak	3·8	W.	...	......	5·2	N. 34° E.	...	......	?
Flat	0·9	W.	...	......	7·7	N. 24° W.			
San Pedro rock	4·6	W.	...	......	8·3	N. 11° W.			
False Cattle Hill	2·5	W.	...	......	6·8	N. 29° W.			
Road	0·9	W.	...	......	8·0	N. 28° W.			
San Bruno Mountain	3·2	E.	...	......	0·8	E. 7° S.			

List of Displacements (*continued*).

Station.	Position relative to Fault.		Displacements.					
			1868.		1906.		Combined.	
	mi.	dir.	ft.	dir.	ft.	dir.	ft.	dir.
Black Bluff	1·6	E.	...	......	1·3	S. 47° E.		
Black Ridge No. 2	4·3	E.	...	......	0·7	S. 19° W.		
Rocky Mound	20	E.	1·6	N. 8° E.	1·1	N. 35° W.	2·6	N. 9° W.
Bonita Point Lighthouse	3·7	E.	...	......	0·7	S. 19° W.	...	...... ?
Farallon Lighthouse ...	23	W.	4·6	N. 27° W.	5·8	N. 62° W.	9·9	N. 47° W.
Mount Tamalpais.........	4·0	E.	5·4	N. 12° W.	1·9	S. 36° E.	3·7	N.
Hammond...	0·7	E.	...	......	...	......	5·7	W. 9° S.
Point Reyes Lighthouse.	12	W.	...	......	3·6	N. 67° W.		
Point Reyes Hill	1·7	W.	...	......	...	......	16·9	N. 30° W.
Hans	0·3	E.	...	......	...	......	2·1	S. 52° W.
Foster	1·2	W.	...	......	...	......	19·7	N. 31° W.
Sonoma Mountain	21	E.	...	......	...	......	4·0	N. 3° E.
Mershon.....................	0·7	E.	...	......	...	......	1·3	S. 30° E.
Tomales Bay..............	1·3	W	...	......	...	......	17·5	N. 30° W.
Tomales Point	1·2	W.	...	......	...	......	16·4	N. 29° W.
Smith	1·0	E.	...	......	...	......	2·1	E. 11° N.
Bodega	1·2	E.	...	......	...	......	3·0	N. 59° E.
Bodega Head..............	1·4	W.	...	......	...	......	17·1	N. 7° W.
Peaked Hill	1·2	E.	...	......	4·2	S. 59° E.		
Ross Mountain	4·3	E.	5·6	N. 2° E.	1·8	S. 51° E.	4·7	N. 19° E.
Chaparral	1·1	E.	...	......	4·4	S. 32° E.		
Dixon.........................	1·1	E.	...	......	4·5	S. 44° E.		
Pinnacle Rock	1·0	W.	...	......	8·1	N. 22° W.		
Fort Ross	1·2	W.	...	......	8·2	N. 33° W.		
Henry Hill	0·9	E.	...	......	4·8	S. 40° E.		
Timber Cove...............	1·2	W.	...	......	7·3	N. 36° W.		
Stockhoff	1·6	W.	...	......	5·9	N. 36° W.		
Funcke	0·2	W.	...	......	7·6	N. 41° W.		
Salt Point..................	2·0	W.	...	......	6·6	N. 42° W.		
Lancaster	1·2	E.	6·0	N. 7° W.	5·8	S. 33° E.	2·7	N. 36° E.
Horseshoe Point	1·8	W.	...	......	4·9	N. 43° W.		
High Bluff	4·2	W.	...	......	9·1	N. 21° W.		
Pt. Arena Catholic Ch. .	3·5	W.	...	......	8·8	N. 17° W.		
Sinclair	4·2	W.	...	......	8·4	N. 19° W.		
Arena...................... ..	4·7	W.	...	......	8·3	N. 19° W.		
Shoemake	0·9	W.	...	......	10·7	N. 16° W.		
Clarke	2·4	E.	...	......	2·7	S. 31° E.		
Pt. Arena Lighthouse ...	4·0	W.	...	......	8·0	N. 19° W.		
Spur	0·3	E.	...	......	5·0	S. 36° E.		
Dunn.........................	2·4	E.	...	......	2·6	S. 31° E.		
Lane	0·1	E.	...	......	5·0	S. 20° E.		

Discussion.

Mr. J. H. Collins said that he was interested to hear the Author's statement that there had been considerable lateral displacement on either side of the San Andreas fault. The fact that

the great majority of lode-displacements—in Cornwall for instance—could be accounted for by a simple 'descent of the hanging wall' had led many students of fault-phenomena in recent years somewhat to underrate the importance of the small minority of cases where lateral and even rotational movements were postulated. This observed fact in California was useful in restoring to some extent the old and broader idea of fault-movement.

Dr. J. W. Evans thought that, although the permanent deformation, to which the Author gave the name mochleusis, and the faulting were no doubt due to a common cause which remained to be determined, yet the vibratory movement or orchesis (as the Author termed it) must be the direct result of the sudden snap or fracture of the strata in faulting.

Mr. G. Barrow, referring to the lateral displacement along a definite line, drew attention to the fact that, in many of the lead-veins of North-West Yorkshire, the sides of the veins were often fluted and 'slickened' in a horizontal rather than in a vertical direction. The frequent occurrence of earthquakes within or on the margin of areas of volcanic activity seemed to the speaker to suggest some connexion of these tremors with igneous intrusions.

Dr. Strahan said that he joined in the discussion on this difficult subject with diffidence, but that he had been interested in hearing a paper in which shocks were not assumed to have originated necessarily in fault-movements. He considered that that theory had been pressed too hard; certainly in some cases the wrong fault had been credited with the effect, while in other cases faults which had no existence had been invented for the occasion. Moreover, no account had been taken of the fact that faults belonged to two wholly different classes. Normal slip-faults, which frequently occurred in pairs as trough-faults, resulted in an expansion of the tract that they traversed, each fault representing a horizontal gain proportionate to its hade and throw. Upwards of a mile had been gained in certain regions, where complete knowledge of the character of the faults had rendered measurement possible. But in other regions overthrust faults prevailed, and had resulted in horizontal contraction. No distinction had been made between these different classes, nor had any reason been assigned why one only, out of a series of closely related faults, should suddenly display activity. It had become customary to call in any fracture which happened to be conveniently situated, whatever its character and whatever its age, to do duty as the 'originating fault.' Moreover, the tracing of the isoseismic lines was founded on evidence which was not wholly convincing. He welcomed, therefore, the alternative explanation of the displacements observable after shocks, which had been so lucidly advanced by the Author.

Prof. Watts quoted the coincidence of the Leicester Fault with the anticlinal fault of Charnwood Forest. Dr. Davison inferred that the hade of this fault must have shifted from one side to the other along the course of the fault. Of the Charnwood-Forest faults, the only one of which the hade would be likely to shift along its course

would be the anticlinal fault, and not any of the several overthrusts which run parallel to it, and this was the one which seemed to correspond with the focal line of the Leicester earthquake.

Prof. Cole asked whether the Author was prepared to locate the origin of large earthquakes at a far greater depth in the crust than Mallet would have proposed. It seemed possible that what were called lines of weakness in the earth's crust, along which movements of the surface might take place, represented lines of weakness in those inaccessible regions that Dr. Ampferer had called the untergrund. Our surface-movements might thus, as Ampferer had urged, have no relation to the characters or disposition of the rock-masses visible to us, but might, unhappily for geological reasoning, depend on those of more active masses entirely beyond our reach.

Mr. J. F. N. Green said that it had been shown that the suggested distribution of stresses was competent to produce a displacement along the line of fault. Such a displacement must necessarily produce vibration, which accounted in any case for at least part of the earthquake, which part might be said to be caused by the fault. He enquired whether there was any evidence that a part of the earthquake remained which could not thus be accounted for.

The Rev. E. C. Spicer asked the Author whether he had arrived at any conclusion with regard to the origin of the forces that produced a series of couples acting horizontally in the earth's crust and producing apparently a 'flaw' rather than a fault.

M. M. Allorge, referring to a stay which he had made in California two years before the earthquake of 1906, said that, although he was unable to investigate the nature of the untergrund, he had nevertheless been impressed by some structural features which tallied very well with the Author's ingenious explanation of recent events. Already at that time the San Andreas fault, along which considerable displacement was to take place two years later, gave rise to unusual features in the topography. Along that 'earthquake-crack,' cutting the coastal ranges obliquely, there were series of low passes, of elongated basins, some of which had reversed slopes or even no outlets. The recent seism had thrown light on the genesis of all these unsystematic topographical featnres, which might be accounted for by a truncation and a lateral displacement of the drainage-system.

The second point that impressed the speaker was the evidence afforded by physiography of the recent and possibly present formation of newer folds off the coast of California. The city of Los Angeles was as much exposed to earthquakes as San Francisco. On a line running south-south-west of Los Angeles was the rocky promontory of San Pedro, formerly an island and now connected with the mainland by a succession of elevated beaches. The island of Santa Catalina, 25 miles off San Pedro, was a maturely dissected sierra, the summit of which alone stood above the waters of the Pacific; submerged valleys and short rios presupposed a recent subsidence. Some 30 miles to the south-south-west lay another island (San Clemente), exhibiting a terraced profile with raised beaches.

It seemed probable that San Pedro corresponded to an anticlinal axis in course of formation, Santa Catalina to a syncline, and San Clemente to another anticlinal ridge.

Pressures great enough to produce these foldings must act at right-angles to the orientation of these islands, that was, north-north-eastwards. When stresses acting in that direction encountered obliquely the great fault ranging from Point Arena to the Mohave Desert, they naturally must have a tendency to be relieved by an horizontal displacement of the proximate lip in a direction away from the acute angle of incidence formed by the direction of the stresses and the strike of the fault, in the way illustrated by the Author's diagrams and experiments.

Mr. L. H. Cooke said that Mr. Collins's suggestion, as to the possibility of 'heaves' having been formed by a relative displacement of the two walls along their strike, deserved special attention in the cases where the walls were slickensided, fluted, and striated horizontally, as was most usual in the lead- and zinc-mines in the Mountain Limestone of Flintshire and Derbyshire according to his (the speaker's) observations. In these districts, the vein-fissures had mostly small 'throws,' and in some instances might possibly be merely enlarged joints in which the sides and filling had been slickensided by repeated to-and-fro movements—a view which seemed in consonance with what had been written by Sir Archibald Geikie. The common allegation that the flutings and striations of slickensides indicated the direction of dislocation had not, so far as he knew, been proved: it seemed a survival of the regrettable practice of confidently putting forward plausible assumptions as proved facts. Since, however, the precise trigonometrical survey in California had demonstrated movement or dislocation along the strike of the fissure, it was very desirable to scrutinize these Flintshire and Derbyshire veins more closely in this respect.

Attention had been previously called to apparent strike-dislocations in highly disturbed rocks (as, for example, in the Lewisian Gneiss), but in such districts some alternative explanation was nearly always possible, and geologists would doubtless be grateful to the trigonometrical surveyors of California for presenting them with incontrovertible proof of such movements.

The century-old J. C. L. Schmidt rule, which postulated a descent of the hanging wall, applied, so far as he had been able to test it, on the lines first indicated by Christian Zimmermann, to the great bulk of heaves in other districts with which he was acquainted.

The President remarked that the Author fully admitted that local earthquakes might arise from tectonic dislocations, and his conclusions only applied to great world-shaking seisms. But, even if it were found impossible to trace the San Francisco earthquake to a particular line of fracture, it by no means followed that the cause was not to be found in a sudden release from a state of strain. The system of forces applied to the material used in the mould would give rise to a fracture inclined at 45° to the direction of the slit which represented the San Francisco fracture. The subject

was one of extreme difficulty ; but the paper, if it did not afford a solution, had at least the merit of raising the question.

The AUTHOR, in reply, said that he was unable to form any conclusion as to the manner in which the stresses were produced, or as to their exact nature. As regarded the connexion of faults with earthquakes, it was undeniable that they often determined a local increase of violence of shock, and to this extent could be regarded as the cause of earthquakes ; but the conclusion to which he had been driven was, that although the presence of pre-existent fractures might determine the localization and distribution of the violence of the shock, the disturbance was really independent of them, and that the position of earthquake-origins and the forces to which they were due were independent of the leading structural features of the district and of the forces and movements by which these were produced.

2. *On the* Fossil Plants *of the* Waldershare *and* Fredville Series *of the* Kent Coalfield.

By E. A. Newell Arber, M.A., F.L.S., F.G.S., Trinity College, Cambridge; University Demonstrator in Palæobotany. (Read November 4th, 1908.)

[Plate I.]

Contents.

I. Introduction.

At the present time, important series of coal-seams have been proved by means of borings in three localities in South-Eastern Kent. As apparently the lithological sequence, including the coal-seams, is quite distinct in each case, we may, as a temporary expedient until the structure of this concealed coalfield can be demonstrated, distinguish them as the Dover, Waldershare, and Fredville Series.

The Dover Series was the first discovered. In 1886, a boring was made at the site of the proposed Channel Tunnel on the foreshore at Shakespeare Cliff, rather more than a mile to the west of the Admiralty pier at Dover. The Coal-Measures were reached in 1890, at a depth of 1100 feet, and the boring subsequently penetrated to a depth of about 2270 feet, passing through thirteen seams of coal, varying from 1 to 4 feet in thickness. The Dover Series is essentially a thin-coal series, and sandstone-beds are comparatively numerous. For many years past attempts have been made to sink shafts, and to work the coals, on or near the site of the original borings, by the Kent Collieries, Limited, but hitherto with small success owing to difficulties in connexion with the inflowing water derived from the Mesozoic rocks. The fossil plants obtained from the original boring through the Dover Series were described by Prof. Zeiller [1] in 1892, and will be further discussed here.

In 1904, a new company, the Kent Coal Concessions, Limited, with which several daughter companies and syndicates have more recently been associated, was formed in order to search for coal to the north of Dover. Early in 1905, a boring was begun at Waldershare Park, about 6 miles north-west of Dover. The Coal-Measures were struck at a depth of 1394 feet from the surface, and the bore penetrated farther through some 1260 feet of the

[1] Zeiller (92). Numerals in parentheses after authors' names indicate the date of the paper to which reference will be found in the Bibliography, § IV, p. 38.

Waldershare Series. A condensed and diagrammatic section of the Carboniferous core is as follows:—

Diagrammatic Section of the Waldershare Series.

Depth in feet (from surface).		*Top of Coal-Measures.*
1394	Sandstones, shales, and underclays. 424 feet.	
1818	Coal.	Welcome Seam (1 ft. 8 ins.).
	Shales and fireclays. 63 feet.	
1881	Coal.	Alexandra Seam (3 ft. 4 ins.).
	Shales and fireclays. 27 feet.	
1908	Coal.	King Edward Seam (4 ft. 6 ins.).
	Shales and fireclays. 48 feet.	
1956	Coal.	Watkin Seam (1 ft. 4 ins.).
	Sandstones and shales. 421 feet.	
2377	Coal.	Rockefeller Seam (5 ft. 2 ins.).
	Continued to 2654 feet.	

The Waldershare Series is essentially a shale-series: sandstone-beds being unimportant, except at the top and near the bottom.

Later in 1905, the same Company put down a boring near Fredville Park, close to the main line of the Chatham & Dover Railway from Dover to Canterbury, and about 2 miles north of Shepherds' Well Station. This boring is distant about 3 miles north-west of the Waldershare boring. The Coal-Measures were struck at a depth of 1363 feet below the surface. Three seams of coal were proved. A condensed and diagrammatic section of this boring is as follows:—

DIAGRAMMATIC SECTION OF THE FREDVILLE SERIES.

Depth in feet (from surface).		*Top of Coal-Measures.*
1363	Shales and one sandstone-bed. 61 feet.	
1424	Coal.	Castor Seam (1 ft. 6 ins.).
	Shales and fireclays. 22 feet.	
1446	Coal.	Pollux Seam (1 ft. 6 ins.).
	Shales, fireclays, and sandstones. 64 feet.	
1510	Coal.	Beresford Seam (4 ft. 4 ins.).
	Continued to 1813 feet.	

The Fredville Series is also a shale-series, but the shales are more sandy than at Waldershare.

The present paper contains an account of the fossil plants collected as the result of a thorough examination of the Waldershare and Fredville cores. I do not propose to discuss here the general questions relating to the geology of the Kent Coalfield, nor to include a detailed account of the beds proved by these borings. These matters have been already dealt with in some detail by Prof. Boyd Dawkins,[1] who had the geological oversight of the borings. In 1907, I was invited by the Kent Coal Concessions, Limited, to undertake the collection and examination of the plant-remains, in order to ascertain if possible the palæobotanical horizons of the two series. This I have been able to do, as will be seen here. I may take this opportunity to acknowledge the facilities and valuable information placed at my disposal for this purpose by Mr. Arthur Burr, Managing Director of the Company, and by Mr. Malcolm Burr, F.G.S., the Resident Engineer of the workings, and I would also express my thanks for the invariable kindness and courtesy which I have received at their hands.

The literature of the fossil flora of the Kent Coalfield is naturally scanty. Prof. Boyd Dawkins[2] states that, in 1892, in a report by Mr. McMurtrie, the conclusion was expressed that the Dover Series belongs to the same horizon as the Radstock and Farrington Series of the Somerset Coalfield. I have not, however, seen this report.

[1] Dawkins (05) (07). [2] Dawkins (05) p. 31.

In the same year Prof. Zeiller[1] contributed a note to the Paris Academy on the plants collected by Mr. Brady from the Dover Boring. Some of these specimens are now in the Geological Department of the British Museum (Natural History).[2]

The following species were obtained:—

At a depth of 1894 feet.

Cf. *Mariopteris sphenopteroides* (Lesq.).
Neuropteris Scheuchzeri, Hoffm.
Neuropteris rarinervis, Bunb.
Neuropteris tenuifolia (Schloth.).
Lepidodendron aculeatum, Sternb.
Cordaicarpus cf. *corculum* (Sternb.).

At a depth of 1900 feet.

Neuropteris Scheuchzeri, Hoffm.
Neuropteris rarinervis, Bunb.
Neuropteris tenuifolia (Schloth.).
Cyclopteris sp.
Calamophyllites Gœpperti (Ett.).
Lepidostrobus variabilis, L. & H.
Cordaicarpus cf. *corculum* (Sternb.).

At a depth of 2038 feet.

Neuropteris Scheuchzeri, Hoffm.
Lepidodendron lycopodioides (Sternb.).
Stigmaria ficoides (Sternb.).

I will discuss the conclusions which Prof. Zeiller draws as to the horizon at a later stage in this paper.

II. Description of the Specimens.

In the following descriptions, only a few, typical references to the literature are given.

Equisetales.

Calamites, Suckow, 1784.

Acta Acad. Elect. Theod. Palat. vol. v, p. 355.

Calamites cf. C. cisti, Brongn.

1828. *Calamites Cistii*, Brongniart, 'Hist. Végét. Foss.' p. 129, pl. xx.
1886–88. *Calamites Cisti*, Zeiller, 'Flore Foss. Bass. Houill. Valenciennes,' p. 342 & pl. lvi, figs. 1–2.

Waldershare Series at 1925 feet.

Fragments of pith-casts of *Calamites* are fairly frequent in the higher part of the Waldershare Series; but, as one would expect from a core with a maximum diameter of only 3 to 4 inches, they are usually too imperfect for determination. In the case of one specimen however, where a node is seen, as well as part of a fairly long internode, the size and shape of the infranodal scars suggest a comparison with *C. cisti*.

[1] Zeiller (92).
[2] Registered numbers, V. 3467–73, V. 3500.

Annularia, Sternberg, 1821.

'Versuch einer Darstell. d. Flora d. Vorwelt' Heft ii, p. 32.

1. Annularia sphenophylloides (Zenker). (Pl. I, fig. 1.)

1833. *Galium sphenophylloides*, Zenker, Neues Jahrb. p. 398 & pl. v, figs. 6–9.
1886–88. *Annularia sphenophylloides*, Zeiller, 'Flore Foss. Bass. Houill. Valenciennes' p. 388 & pl. lx, figs. 5–6.

Waldershare Series at 1512, ? 1527, 1840, 1843, 1850, 1869, 2211, 2216, & 2397 feet.
Fredville Series at 1387 feet.

This species is quite abundant in the Waldershare Series. The size of the leaves, however, is much greater than in the case of any other specimens that I have previously seen. In a typical specimen from the Radstock Series of the Somerset Coalfield, the length of the leaf is about 4 or 5 millimetres. In the examples from Kent, the leaf is 8 to 10 millimetres long. Yet in other respects these two plants appear to me to be identical. The shape of the leaf is very similar, but the apex appears to be slightly broader and more truncate. It may be that more than one species of Calamite-stem bore leaves of this type, which when isolated can hardly be distinguished one from the other; but, at present, I do not find any good grounds for regarding the specimens from Kent as distinct from those of the Coal-Measures of other parts of England.

2. Annularia stellata (Schloth.).

1820. *Casuarinites stellatus*, Schlotheim, 'Petrefactenkunde' p. 397.
1855. *Annularia longifolia*, Geinitz, 'Verstein. d. Steinkohlf. in Sachsen' p. 10 & pl. xviii, figs. 8–9; also pl. xix, figs. 3–5.
1886–88. *Annularia stellata*, Zeiller, 'Flore Foss. Bass. Houill. Valenciennes' p. 398 & pl. lxi, figs. 3–6.

Waldershare Series at 1931 & ? 1862 feet.

Sphenophyllales.

Sphenophyllum, Brongniart, 1828.

'Prodr. Hist. Végét. Foss.' p. 68.

Sphenophyllum cuneifolium (Sternb.).

1821. *Rotularia cuneifolia*, Sternberg, 'Versuch einer Darstell. d. Flora d. Vorwelt' Heft ii, p. 33 & pl. xxvi, figs. 4 *a*–4 *b*.
1886–88. *Sphenophyllum cuneifolium*, Zeiller, 'Flore Foss. Bass. Houill. Valenciennes' p. 413 & pl. lxii, fig. 1; also pl. lxiii, figs. 1–10.
1893. *Sphenophyllum cuneifolium*, Zeiller, Mém. Soc. Géol. France, Paléont. Mém. vol. iv, no. 11, p. 12 & pl. i, figs. 1–4, pl. ii, figs. 1–3, pl. iii, figs. 1–2.

Waldershare Series at 1841 & 1848 feet.
Fredville Series at 1490 feet.

Leaves and stems of *Sphenophyllum* are of common occurrence in both cores, but the specimens are as a rule fragmentary. The apices of the leaves are usually broken or badly preserved, hence many of the specimens cannot be determined specifically. Such fragments occur in the Waldershare core at 1761, 1830, 1835, 1836, 1838, 1839, 1842, 1843, 1863, 1871, and 1901 feet.

Filicales and Pteridospermeæ.

Neuropteris, Brongniart, 1822.

Sur la Class. des Végét. Foss.' (Mém. Mus. Hist. Nat. vol. viii) p. 233.

1. Neuropteris scheuchzeri, Hoffm.

1826. *Neuropteris Scheuchzeri*, Hoffmann, in Keferstein's 'Teutschland geognost. geol. dargestellt.' vol. iv, p. 156 & pl. i *b*, figs. 1–4.
1886–88. *Neuropteris Scheuchzeri*, Zeiller, 'Flore Foss. Bass. Houill. Valenciennes' p. 251 & pl. xli, figs. 1–3.
1887. *Neuropteris Scheuchzeri*, Kidston, Trans. Roy. Soc. Edinb. vol. xxxiii, pt. ii, p. 356 & pl. xxiii, figs. 1–2.

Waldershare Series at 1512, 1762, 1773, 1824, 1826, 1827, 1830, 1838, 1842, 1863, 1871, 1897, & 2365 feet.
Fredville Series at 1390 & 1454 feet.

This fossil is by far the commonest plant in all the beds passed through in the Waldershare boring, and it is often extraordinarily abundant. The pinnules are, as is usually the case, nearly all detached, but one example shows the smaller accessory pinnules still in continuity at the base of one of the larger leaflets. In the Fredville Series *N. scheuchzeri* appears to be less frequent, though it is abundant in certain beds.

2. Neuropteris rarinervis, Bunbury. (Pl. I, fig. 2.)

1847. *Neuropteris rarinervis*, Bunbury, Quart. Journ. Geol. Soc. vol. iii, p. 425 & pl. xxii.
1886–88. *Neuropteris rarinervis*, Zeiller, 'Flore Foss. Bass. Houill. Valenciennes' p. 268 & pl. xlv.

Waldershare Series, at ? 1761, 1762, ? 1763, ? 1764, ? 1826, 1840, ? 1841, 1955, 2280, 2392, & 2397 feet.
Fredville Series at 1421, 1454, ? 1501, & 1502 feet.

The plant is quite abundant in the Waldershare, and also common in the Fredville Series.

3. Neuropteris tenuifolia (Schloth.). (Pl. I, fig. 7.)

1820. *Filicites tenuifolius*, Schlotheim, 'Petrefactenkunde' p. 405 & pl. xxii, fig. 1.
1830–32. *Neuropteris tenuifolia*, Brongniart, 'Hist. Végét. Foss.' vol. i, p. 241 & pl. lxxii, fig. 3.
1886–88. *Neuropteris tenuifolia*, Zeiller, 'Flore Foss. Bass. Houill. Valenciennes' p. 273 & pl. xlvi, fig. 1.

Waldershare Series at 1863, ? 1864, ? 1883, & 1903 feet.
Fredville Series at 1407 feet.

4. Neuropteris obliqua (Brongniart). (Pl. I, fig. 3.)

1832–34. *Pecopteris obliqua*, Brongniart, 'Hist. Végét. Foss.' vol. i, p. 320 & pl. xcvi, figs. 1–4.
1886–88. *Neuropteris obliqua*, Zeiller, 'Flore Foss. Bass. Houill. Valenciennes' p. 284 & pl. xlviii, figs. 1, 2, ? 3, 4–7.

Waldershare Series at ? 1934, 2277, 2367, & 2402 feet.

5. Neuropteris (Cyclopteris) sp.

Waldershare Series at 1826, 1830, & 1834 feet.
Fredville Series at 1391 feet.

The large, adventitious, orbicular pinnules, borne on the rachis

of certain Neuropterids, are met with occasionally in various beds in both series. It is not, however, possible at present, owing to the fragmentary condition in which all fossil plants occur, to refer them to the species of frond that bore them.

ODONTOPTERIS, Brongniart, 1822.

'Sur la Class. des Végét. Foss.' (Mém. Mus. Hist. Nat. vol. viii) p. 234.

ODONTOPTERIS LINDLEYANA, Sternberg. (Pl. I, fig. 4.)

1831. *Odontopteris obtusa*, Lindley & Hutton, 'Foss. Flora,' vol. i, p. 117 & pl. xl.
1833. *Odontopteris Lindleyana*, Sternberg, 'Versuch einer Darstell. d. Flora d. Vorwelt' Heft. v–vi, p. 78.

Waldershare Series at 1845, 1848, 1871, 1873, & 1898 feet.

This plant, which is not infrequent in the Waldershare Series, has been so rarely figured, that I include a figure of the best specimen from Kent on Pl. I, fig. 4. Dr. Kidston [1] has stated that the figure given by Lindley & Hutton 'is not a very correct representation of the specimen.'

ALETHOPTERIS, Sternberg, 1826.

'Versuch einer Darstell. d. Flora d. Vorwelt' Heft iv, p. xxi.

1. ALETHOPTERIS LONCHITICA (Schloth.).

1820. *Filicites lonchiticus*, Schlotheim, 'Petrefactenkunde' p. 411.
1832–34. *Pecopteris lonchitica*, Brongniart, 'Hist. Végét. Foss.' vol. i, p. 275 & pl. lxxxiv, figs. 1–7; also pl. cxxviii.
1886–88. *Alethopteris lonchitica*, Zeiller, 'Flore Foss. Bass. Houill. Valenciennes' p. 225 & pl. xxxi.

Waldershare Series at 1826, 1842, & 1848 feet.
Fredville Series at 1398, 1400, ? 1403, 1405, 1410, 1412, 1415, & 1502 feet.

This species appears to be more abundant in the Fredville than in the Waldershare Series.

2. ALETHOPTERIS SERLI (Brongn.).

1832–34. *Pecopteris Serlii*, Brongniart, 'Hist. Végét. Foss.' vol. i, p. 292 & pl. lxxxv.
1837. *Pecopteris Serlii*, Lindley & Hutton, 'Foss. Flora' vol. iii, p. 139 & pl. ccii.
1886–88. *Alethopteris Serli*, Zeiller, 'Flore Foss. Bass. Houill. Valenciennes' p. 234 & pl. xxxvi, figs. 1–2; also pl. xxxvii.

Fredville Series at ? 1410, 1415, & 1416 feet.

This species appears to be rare, or at any rate much less abundant than *A. lonchitica* (Schloth.).

TRIGONOCARPUS, Brongniart, 1828.

'Prodr. Hist. Végét. Foss.' p. 137.

TRIGONOCARPUS sp.

Waldershare Series at 1773 feet.
Fredville Series at 1387 feet.

These specimens of seeds, which in some respects resemble certain states of preservation of *Trigonocarpus parkinsoni*, are too badly preserved to be specifically identified.

[1] Kidston (87) p. 363.

Pecopteris, Brongniart, 1822.

'Sur la Class. des Végét. Foss.' (Mém. Mus. Hist. Nat. vol. viii) p. 233.

1. Pecopteris miltoni (Artis).

1825. *Filicites Miltoni*, Artis, 'Antediluvian Phytology' pl. xiv.
1835. *Pecopteris abbreviata*, Brongniart, 'Hist. Végét. Foss.' vol. i, p. 337 & pl. cxv, figs. 1–4.
1886–88. *Pecopteris* (*Asterotheca*) *abbreviata*, Zeiller, 'Flore Foss. Bass. Houill. Valenciennes' p. 186 & pl. xxiv.
1887. *Pecopteris Miltoni*, Kidston, Trans. Roy. Soc. Edinburgh, vol. xxxiii, p. 374 & text-figs. 2–5 *a*.

Waldershare Series at 1761, ? 1764, 1863, ? 1864, 1866, 1868, 1871, 1873, ? 1874, 1876, & 1897 feet.
Fredville Series at 1390 & 1391 feet.

This fossil is very abundant in the Waldershare Series. Most of the specimens are of the '*abbreviata*'-type, which Dr. Kidston unites with *P. Miltoni*, as I think correctly.

2. Pecopteris arborescens ? (Schloth.).

1820. *Filicites arborescens*, Schlotheim, 'Petrefactenkunde' p. 404.
1833–34. *Pecopteris arborescens*, Brongniart, 'Hist. Végét. Foss.' vol. i, p. 310 & pl. cii, figs. 1–2; also pl. ciii, figs. 2–3.
1890. *Pecopteris* (*Asterotheca*) *arborescens*, Zeiller, 'Bassin Houiller & Permien d'Autun & d'Épinac' fasc. ii, pt. i, p. 43 & pl. viii, fig. 1.

Waldershare Series at ? 1903 feet.

The occurrence of this species is doubtful. Only a single specimen has been observed, which shows two fragments of Pecopterid fronds, the one fertile and agreeing very well with the fertile leaves of *P. arborescens*, and the other sterile. In the latter, the nervation can just be made out, but not very clearly. The lateral nerves, however, appear to be simple, and this would suggest that the specimen may be provisionally referred to this species.

Mariopteris, Zeiller, 1879.

Bull. Soc. Géol. France, ser. 3, vol. vii, p. 92.

Mariopteris muricata (Schloth.), var. nervosa (Brongn.). (Pl. I, fig. 6.)

1828. *Pecopteris nervosa*, Brongniart, 'Hist. Végét. Foss.' vol. i, p. 297 & pl. xcv, figs. 1, 1 *a*, 1 *b*, 2, 2 *a*.
1855. *Alethopteris nervosa*, Geinitz, 'Verstein. d. Steinkohlenf. in Sachsen' p. 30 & pl. xxxiii, figs. 2–2 *a*.
1886–88. *Mariopteris muricata*, forme *nervosa* Zeiller, 'Flore Foss. Bass. Houill. Valenciennes' p. 173 & pl. xx, fig. 1; pl. xxii, fig. 1; also pl. xxiii.

Waldershare Series at 1825, 1830, 1833, 1838, 1872, & 1883 feet.

These fragmentary specimens (Pl. I, fig. 6) have very strong nerves, like those figured by Brongniart (see above). The habit of the frond, however, is more closely comparable with that of the specimen figured by Prof. Zeiller, in his Valenciennes flora (pl. xxii, fig. 2), which unites in some measure the characters of the two varieties *typica* and *nervosa*.

SPHENOPTERIS, Brongniart, 1822.

'Sur. la Class. des Végét. Foss.' (Mém. Mus. Hist. Nat. vol. viii) p. 233.

SPHENOPTERIS NEUROPTEROIDES (Boulay). (Pl. I, fig. 8.)

1876. *Pecopteris neuropteroides*, Boulay, 'Terr. Houill. du Nord de la France' p. 32 & pl. ii, figs. 6–6 bis.
1886–88. *Sphenopteris neuropteroides*, Zeiller, 'Flore Foss. Bass. Houill. Valenciennes' p. 70 & pl. ii, figs. 1–2 *a*.

Waldershare Series at 1845 & ? 1850 feet.
Fredville Series at 1458 feet.

These specimens are only small fragments of pinnæ (Pl. I, fig. 8); but, so far as one can judge, they agree closely with this species.

EREMOPTERIS, Schimper, 1869.

'Traité Pal. Végét.' vol. i, p. 416.

EREMOPTERIS cf. E. ARTEMISIÆFOLIA (Sternberg).

1826. *Sphenopteris artemisiæfolia*, Sternberg, 'Versuch einer Darstell. d. Flora d. Vorwelt' Heft iv, p. xv, & pl. liv, fig. 1 (1826); also Heft vii, p. 58 (1838).
1829. *Sphenopteris artemisiæfolia*, Brongniart, 'Hist. Végét. Foss.' vol. i, p. 176 & pls. xlvi–xlvii.
1832. *Sphenopteris crithmifolia*, Lindley & Hutton, 'Foss. Flora' vol. i, pl. xlvi.
1869. *Eremopteris artemisiæfolia*, Schimper, 'Traité Pal. Végét.' vol. i, p. 416 & pl. xxx, fig. 4.

Waldershare Series at 1933 & ? 2297 feet.

Some fragments of pinnæ from the Waldershare Series agree rather closely, as regards both form and nervation, with specimens of this species from the Newcastle & Durham Coalfield. They are, however, too imperfect to be identified with certainty. But their identity with *Eremopteris artemisiæfolia*, hitherto one of the most local of Carboniferous plants, is further rendered probable by the fact that seeds, which are almost certainly the *Cardiocarpus acutus* of Lindley & Hutton, occur in the same core, though at a lower level. There are strong reasons to believe that *C. acutus* is the seed of *Eremopteris artemisiæfolia*, although the fact has not yet been proved.

Semina incertæ sedis.

CARDIOCARPUS, Brongniart, 1828.

'Prodr. Hist. Végét. Foss.' p. 87.

CARDIOCARPUS ACUTUS, Lindley & Hutton (? Brongniart). (Pl. I, fig. 5.)

1833. *Cardiocarpus acutus*, Lindley & Hutton, 'Foss. Flora' vol. i, p. 209 & pl. lxxvi.

Waldershare Series at 2425 feet.

These seeds (Pl. I, fig. 5) are very characteristic, and are frequently associated with *Eremopteris artemisiæfolia* (Sternb.) in the Newcastle & Durham Coalfield. There is a strong probability that this frond belonged to a Pteridosperm, of which this was the seed, but at present it is not possible to prove that such was the

case. The specimens from Kent (Pl. I, fig. 5) agree very well with those from the coalfield above mentioned, and also with the seeds figured by Brongniart in his 'Histoire' (pl. xlvi) in association with this frond.

Lycopodiales.

Lepidodendron, Sternberg, 1820.

'Versuch einer Darstell. d. Flora d. Vorwelt' Heft i, p. 23.

Lepidodendron sp.

Fredville Series at 1391 feet.

A much decorticated specimen of a *Lepidodendron* has been obtained from this series, and also some young twigs clothed with leaves, but neither can be identified specifically.

Lepidophyllum, Brongniart, 1828.

'Prodr. Hist. Végét. Foss.' p. 87.

Lepidophyllum lanceolatum, Lindley & Hutton.

1831 *Lepidophyllum lanceolatum*, Lindley & Hutton, 'Foss. Flora' vol. i, p. 28 & pl. vii, figs. 3–4.
1886–88. *Lepidophyllum lanceolatum*, Zeiller, 'Flore Foss. Bass. Houill. Valenciennes' p. 505 & pl. lxxvii, figs. 7–8 *b*.

Waldershare Series at ? 1955 feet.
Fredville Series at 1408 & ? 1468 feet.

Stigmaria, Brongniart, 1822.

'Sur la Class. des Végét. Foss.' (Mém. Mus. Hist. Nat. vol. viii) p. 209.

Stigmaria ficoides (Sternb.).

1820. *Variolaria ficoides*, Sternberg, 'Versuch einer Darstell. d. Flora d. Vorwelt' Heft i, pp. 22, 24, & pl. xii, figs. 1–3.
1832. *Stigmaria ficoides*, Lindley & Hutton, 'Foss. Flora' vol. i, p. 93 & pls. xxxi–xxxvi; also vol. iii (1835) p. 47 & pl. clxvi.
1886–88. *Stigmaria ficoides*, Zeiller, 'Flore Foss. Bass. Houill. Valenciennes' p. 611 & pl. xci, figs. 1–6.

Waldershare Series at 1771 feet.
Fredville Series at 1398 & 1400 feet.

Stigmarian rootlets are often extremely abundant in many of the beds passed through by both bores, and especially in the fireclays. The highest bed in the Waldershare Series containing these rootlets is at 1435 feet, and in the Fredville Series at 1392 feet. In both cases these are practically the first plant-remains met with in the cores.

Cordaitales.

Cordaites, Unger, 1850.

'Gen. et Spec. Plant. Foss.' p. 277.

Cordaites principalis (Germar).

1848. *Flabellaria principalis*, Germar, 'Verst. Steink. Wettin u. Löbejün' p. 55 & pl. xxiii.
1886–88. *Cordaites principalis*, Zeiller, 'Flore Foss. Bass. Houill. Valenciennes' p. 629 & pl. xciii, fig. 3; also pl. xciv, fig. 1.
1893. *Cordaites principalis*, Kidston, Trans. Roy. Soc. Edinburgh, vol. xxxvii, p. 352 & pl. ii, figs. 8–8 *a*; also pl. iv, figs. 16–17.

Waldershare Series at 1900, ? 1901, 1903, 1922, 1934, 1950, 1954, & 2170 feet.
Fredville Series at 1400 feet.

The fragments of Cordaitean leaves in these cores appear to me to be probably referable to this species, but there is a possibility that, in the Waldershare core, others may belong to *Cordaites angulosostriatus*, Grand 'Eury.

Cordaicarpus, Grand'Eury, 1877.

'Flore Carbon. Loire, &c.' p. 233. (Mém. Div. Sav. Acad. Sci. Paris.)

Cordaicarpus sp.

Waldershare Series at 1766 feet.

Small seeds, about 6 millimetres in length, of the type of *Cordaicarpus gutbieri*, Geinitz, and *C. ovatus*, Brongn.

III. The Horizon.

On the next page a complete list is tabulated of the species recorded from the Kent Coalfield, including, in addition to those from the Waldershare and Fredville Series described here, the records from the Dover Series, given by Prof. Zeiller.[1]

Comparing the plants from the Waldershare and Fredville cores, it will be seen that, with the following exceptions, all the more abundant and characteristic species are common to both series. *Annularia stellata* (Schloth.), *Neuropteris obliqua* (Brongn.), *Odontopteris lindleyana*, Sternb., *Mariopteris muricata* var. *nervosa*, Brongn., are the more important species which have not been found in the Fredville core. On the other hand, two Fredville species have not been recorded from Waldershare:—*Alethopteris serli* (Brongn.), and possibly *Lepidophyllum lanceolatum*, L. & H. The general agreement of the two floras is, however, striking, and leads to the conclusion that the Waldershare and the Fredville Series both belong to the same horizon. The fact that the Waldershare core has yielded a rather larger number of species than that from Fredville is not surprising, seeing that this boring was carried

[1] Zeiller (92).

The Fossil Flora of the Waldershare, Fredville, and Dover Series.	Waldershare Series.	Fredville Series.	Dover Series.
Equisetales.			
Calamites cf. *cisti*, Brongn.	×	...	...
Calamophyllites gœpperti (Ett.)	...	...	×
Annularia sphenophylloides (Zenker)	×	×	...
Annularia stellata (Schloth.)	×	...	...
Sphenophyllales.			
Sphenophyllum cuneifolium (Sternb.)	×	×	...
Filicales and Pteridospermeæ.			
Neuropteris scheuchzeri, Hoffm.	×	×	×
Neuropteris rarinervis, Bunb.	×	×	×
Neuropteris tenuifolia (Schloth.)	×	×	×
Neuropteris obliqua (Brongn.)	×	...	...
Neuropteris (*Cyclopteris*) sp.	×	×	×
Odontopteris lindleyana, Sternb.	×	...	...
Alethopteris lonchitica (Schloth.)	×	×	...
Alethopteris serli (Brongn.)	...	×	...
Trigonocarpus sp.	×	×	...
Pecopteris miltoni (Artis)	×	×	...
Pecopteris arborescens ? (Schloth.)	?	...	...
Mariopteris muricata (Schloth.) var. *nervosa*, Brongn.	×	...	...
Cf. *Mariopteris sphenopteroides* (Lesq.)	...	...	×
Sphenopteris neuropteroides (Boulay)	×	×	...
Eremopteris cf. *E. artemisiæfolia* (Sternb.)	×	...	...
Cardiocarpus acutus, L. & H.	×	...	...
Lycopodiales.			
Lepidodendron sp.	...	×	...
Lepidodendron aculeatum, Sternb.	...	...	×
Lepidodendron lycopodioides (Sternb.)	...	...	×
Lepidophyllum lanceolatum, L. & H.	?	×	...
Lepidostrobus variabilis, L. & H.	...	...	×
Stigmaria ficoides (Sternb.)	×	×	×
Cordaitales.			
Cordaites principalis (Germar)	×	×	...
Cordaicarpus sp.	×	...	...
Cordaicarpus cf. *C. corculum* (Sternb.)	...	...	×

much farther into the Coal-Measures, and that the core itself offers a more favourable collecting-ground. When it is also remembered that the core is only 3 inches or less in diameter, the absence of some of the rarer Waldershare species, such as *Eremopteris* cf. *E. artemisiæfolia* (Sternb.), from the Fredville core is easily accounted for. On the whole, the agreement is very close.

The most abundant species in the Waldershare Series are :—

Neuropteris scheuchzeri, Hoffm.
Neuropteris rarinervis, Bunb.
Annularia sphenophylloides (Zenker).
Pecopteris miltoni (Artis).
Cordaites principalis (Germar).

Neuropteris obliqua (Brongn.), *Odontopteris lindleyana*, Sternb., and *Mariopteris muricata* var. *nervosa* (Brongn.) are not infrequent.

In the Fredville Series, *Alethopteris lonchitica* (Schloth.) is the only species that occurs frequently, but *Neuropteris rarinervis*, Bunb. is not uncommon.

The following table shows the distribution of the Kent species, described here, in the Coal-Measures elsewhere in Britain :—

Name of Species.	Lower Coal-Measures.	Middle Coal-Measures.	Upper Transition Series.	Upper Coal-Measures.
Calamites cf. *cisti*, Brongn.	×	×	×	×
Annularia sphenophylloides (Zenker)	...	×	×	×
Annularia stellata (Schloth.)	...	...	×	×
Sphenophyllum cuneifolium (Sternb.)	×	×	×	...
Neuropteris scheuchzeri, Hoffm.	...	×	×	×
Neuropteris rarinervis, Bunb.	...	×	×	×
Neuropteris tenuifolia (Schloth.)	...	×	×	...
Neuropteris obliqua (Brongn.)	×	×	×	...
Odontopteris lindleyana, Sternb.	...	...	×	×
Alethopteris lonchitica (Schloth.)	×	×	×	×
Alethopteris serli (Brongn.)	...	×	×	×
Pecopteris miltoni (Artis)	×	×	×	×
Pecopteris arborescens ? (Schloth.)	...	...	×	×
Mariopteris muricata, var. *nervosa*, Brongn.	×	×	?	×
Sphenopteris neuropteroides (Boulay)	...	...	×	×
Eremopteris cf. *E. artemisiæfolia* (Sternb.)	×	×	...	...
Cardiocarpus acutus, L. & H.	×	×	...	...
Lepidophyllum lanceolatum, L. & H.	...	×	×	×
Stigmaria ficoides (Sternb.)	×	×	×	×
Cordaites principalis (Germar)	×	×	×	...

It will be seen from this list that several species have been recorded from all four horizons. But, in such cases, they are nearly always much more abundant on some horizons than on others. *Alethopteris lonchitica* (Schloth.), for instance, is more characteristic of the Lower and Middle Coal-Measures than of the higher series. The majority of the species tabulated are either confined to the Upper Coal-Measures and the Transition Series, or are Middle and Lower Coal-Measure plants which are also known to occur in the Transition Series. All the plants have been already recorded from the latter horizon, except, so far as I am aware, *Eremopteris artemisiæfolia* (Sternb.) and the seed *Cardiocarpus acutus*, L. & H.

We thus find in the Waldershare and Fredville Series the mixture of Upper Coal-Measure and Middle Coal-Measure species, which is characteristic of the flora of the Upper Transition Series. *Annularia stellata* (Schloth.) and *A. sphenophylloides* (Zenker), the latter occurring infrequently in the Middle Coal-Measures, *Neuropteris rarinervis*, Bunb., *Odontopteris lindleyana*, Sternb., *Alethopteris serli* (Brongn.), *Pecopteris arborescens?* (Schloth.), and *Sphenopteris neuropteroides* (Boulay) are all typical Upper Coal-Measure species. *Neuropteris scheuchzeri*, Hoffm., like *N. rarinervis* (Bunb.), is probably more abundant generally in the Transition Series and Upper Coal-Measures than in the Middle, while *Alethopteris serli*, Brongn., is very infrequent in the Middle Coal-Measures. *Pecopteris miltoni* (Artis) appears to be almost equally abundant in the three upper horizons, though perhaps somewhat less so in the Middle Coal-Measures than in the higher series.

On the other hand, in *Sphenophyllum cuneifolium* (Sternb.), *Neuropteris tenuifolia* (Schloth.), *N. obliqua* (Brongn.), *Alethopteris lonchitica* (Schloth.), *Cordaites principalis* (Germar), and *Eremopteris artemisiæfolia* (Sternb.), we find species which are chiefly abundant in the Middle, or in both the Middle and Lower Coal-Measures.

The horizon of the Waldershare, and also of the Fredville Series, is thus the Upper Transition Series,[1] and these beds are consequently the homotaxial equivalents of the following deposits in other British coalfields:—

Coalfield.	Series.
North Staffordshire[1]	Newcastle-under-Lyme. Etruria Marl. Blackband Group.
South Staffordshire[2]	Hamstead Colliery, Great Barr, below 1233 feet.
Denbighshire[3]	Cœdyrallt. Ruabon Marls.
South Lancashire[4]	Ardwick Series. Bradford Colliery, above the Bradford Four-foot Coal.
South Wales[5]	Lower Pennant Grit.
Somerset[6]	New Rock. Vobster.

We may now compare the floras of the Waldershare and Fredville Series with that of the Dover Series. The species recorded by Prof. Zeiller, see p. 24, were not sufficiently numerous to indicate the horizon directly. In 1892, he concluded provisionally, chiefly from the occurrence of *Neuropteris rarinervis*, Bunb. and *N. scheuchzeri*, Hoffm., that the Dover Series belonged to the upper region of the Middle Coal-Measures ('Houiller moyen'), and was not

[1] The 'Staffordian' of Dr. Kidston's new classification (05) p. 320, which however I am unable to accept, see p. 37.

[2] Kidston (05) p. 313.

[3] *Id.* (05) p. 314.

[4] Arber (03); Gerrard (04); Kidston (05) p. 320.

[5] Kidston (94) pp. 573–74.

[6] *Id.* (87).

more recent than the Radstock Series of Somerset, or more ancient than the lowest beds of the upper zone, containing the 'Charbons gras et flénus' of the Pas-de-Calais Coalfield.[1] It may be remarked however that, in 1892, the Upper Transition Series had not yet been marked out as a horizon distinct from the Middle and Upper Coal-Measures, and that the North Staffordshire Series, which, as Prof. Zeiller pointed out, contains these two species, was then termed 'Upper Coal-Measures,' though now referred to the Transition Measures.

Two years later, however, Prof. Zeiller[2] correlated the Dover Beds with the Upper Zone of the Pas-de-Calais Coalfield, since eight of the eleven species recorded by him from the former occur in the latter. This zone, that is, 'Zone C,' or the 'Charbons gras et flénus,' was also found to be the equivalent of the British Transition Series in the same year.[3] Thus the Dover Series has been shown, indirectly, to belong to the Transition Series.

From the table given on p. 32 it will be seen that three important species from Dover, among others, occur in both the Waldershare and the Fredville Series. Two of these, *Neuropteris rarinervis*, Bunb. and *N. scheuchzeri*, Hoffm., are Upper Coal-Measure plants, while *N. tenuifolia* (Schloth.) is essentially a Middle Coal-Measure species. Thus such agreement as exists between these floras indicates that all three series belong to the same horizon.

Comparing the floras of the Waldershare and Fredville Series with those of the Pas de Calais and Nord de France (Valenciennes), the nearest Continental coalfields (see table on p. 36), we find that the great majority of the species are common to the highest zone in the Pas de Calais.[4]

The only species absent from the French coalfields are *Odontopteris lindleyana*, Sternb., *Pecopteris arborescens* (Schloth.), a doubtful record from the Waldershare core, *Eremopteris artemisiæfolia* (Sternb.), *Cardiocarpus acutus*, L. & H., and *Cordaicarpus corculum* (Sternb.). On the other hand, the close agreement of the Kent flora with that of 'Zone C,' or the 'Charbons gras et flénus,' of the Pas-de-Calais Coalfield,[5] leads to the conclusion that the horizon of the Waldershare and Fredville Series is homotaxial with this, the highest, zone in that coalfield. Thus the horizon indicated by a comparison with the floras of other British coalfields is confirmed: for, as Prof. Zeiller[6] has shown, the 'Charbons gras et flénus' of the Pas de Calais are to be regarded as equivalent to the British Transition Measures. This horizon is not represented in the Nord-de-France Coalfield.

Looked at broadly, the Kent Coalfield is of especial interest, as adding another link to the chain of coalfields which stretches from Westphalia to the western coast of Wales. There are good grounds for the belief that a more or less continuous sheet of Carboniferous

1 Zeiller (92) p. 629. 2 *Id.* (94[2]) p. 123. 3 *Id.* (94[1]) p. 495.
4 Boulay (76); Zeiller (88), (94[1]). 5 Zeiller (94[1]) p. 490.
6 Zeiller (94[1]) p. 495.

Distribution of the Kent Species in the Pas-de-Calais and Nord-de-France Coalfields.

Name of Species.	Pas-de-Calais Zones.[1]			Nord-de-France Zones.[1]	
	A	B	C	A	B
Calamites cf. *cisti*, Brongn.	...	×	×	×	×
Calamophyllites gœpperti (Ett.)	...	...	...	...	×
Annularia sphenophylloides (Zenker)	...	...	×	...	...
Annularia stellata (Schloth.)	...	...	×	...	...
Sphenophyllum cuneifolium (Sternb.)	...	×	×	×	×
Neuropteris scheuchzeri, Hoffm.	...	×	×	...	...
Neuropteris rarinervis, Bunb.	...	×	×	...	...
Neuropteris tenuifolia (Schloth.)	...	×	×	...	×
Neuropteris obliqua (Brongn.)	...	×	×	×	×
Odontopteris lindleyana, Sternb.	...	...	...	...	...
Alethopteris lonchitica (Schloth.)	...	×	...	×	×
Alethopteris serli (Brongn.)	...	×	×	...	×
Pecopteris miltoni (Artis)	...	×	×	...	×
Pecopteris arborescens ? (Schloth.)	...	...	...	...	..
Mariopteris muricata (Brongn.)	×	×	×	×	×
Cf. *Mariopteris sphenopteroides* (Lesq.)	...	...	×	...	...
Sphenopteris neuropteroides (Boulay)	...	×	×	...	×
Eremopteris cf. *E. artemisiæfolia* (Sternb.)	...	...	...	...	...
Cardiocarpus acutus, L. & H.	...	...	...	...	...
Lepidodendron aculeatum, Sternb.	...	×	×	×	×
Lepidodendron lycopodioides (Sternb.)	...	...	×	...	×
Lepidophyllum lanceolatum, L. & H.	...	×	×	×	×
Lepidostrobus variabilis, L. & H.	...	×	×	...	×
Stigmaria ficoides (Sternb.)	...	×	×	×	×
Cordaites principalis (Germar)	...	...	×	...	×
Cordaicarpus cf. *C. corculum* (Sternb.)	...	...	...	...	...

rocks at one time covered a wide area in Westphalia, Belgium, the North of France, Southern and Western England and Wales.[2] At the close of Carboniferous times, this sheet was thrown into a series of folds or detached basins, as the result of great earth-movements affecting the whole area. These coalfields, though now much denuded, bear a distinct relation to the axis of uplift, which is known as the Mendip-Artois Axis. Godwin-Austen[3] in 1855 showed that the above-mentioned Continental coalfields conform to the Artois Axis, and that this axis could be traced into the south-eastern counties of England. His prophecy that Carboniferous rocks would one day be proved beneath the Mesozoic strata in this district has been abundantly justified. Prof. Boyd Dawkins[4] has confirmed the conclusion that the Mendip Axis is a continuation of the 'Axis of Artois,' and has traced it into Pembrokeshire.

The Westphalian, the Belgian, the Nord-de-France and Pas-de-Calais, the Kent, Somerset, Bristol, Forest of Dean, and South-

[1] See Zeiller (94[1]) and (88).
[2] Godwin-Austen (71).
[3] *Id.* (56) & (71).
[4] Boyd Dawkins (05) p. 32, &c.; (07) p. 455.

Wales Coalfields, and the barren coalfield of Devon & Cornwall, all lying to the north or south of this great east-and-west axis, may be regarded as a succession of basins, distinct, at least tectonically, from the Pennine system of coalfields in the Midlands and the North of England. This group is worthy of further study as a whole, from a broad standpoint, and this remark is especially applicable in regard to the fossil flora. At present, our knowledge of the plants of these coalfields is still very imperfect. One deduction of great interest may, however, be drawn provisionally.

The fossil flora of these rocks belongs to the lower of the two great continental zones of the Upper Carboniferous, widely known on the Continent as the Westphalian. This term has been in use since 1892,[1] in a far broader sense than that recently proposed by Dr. Kidston,[2] who would adopt it as a name for the palæobotanical zone generally known in this country as the Middle Coal-Measures—a fact which militates against the acceptance of his new scheme of zonal nomenclature. The British Middle Coal-Measures is only one horizon in the Westphalian, and further it is a local horizon, which is not as a rule to be traced over wide areas; whereas what may be termed a continental zone is found to be constant over continents or hemispheres.

Though the higher continental zone, the Stephanian, is not represented in the Mendip-Artois series of basins, we have, however, in England and Wales, what may perhaps be a transition between the Westphalian and the Stephanian, in our Upper Coal-Measures.

It appears to be a moot point at present, how far any equivalents of the Lower Coal-Measure horizon of the Pennine and Scottish series of basins can be recognized in the Continental coalfields of the Artois system, though Prof. Zeiller[3] finds that such equivalents do occur in the Nord-de-France Coalfield and in Westphalia. The great bulk of the measures in Westphalia, Belgium, the Nord de France, and to a less extent in the Pas de Calais, appear, beyond doubt, to be Middle Coal-Measures. Certainly in Southern England and South Wales no Lower Coal-Measures have yet been recognized in a palæobotanical sense, although Middle Coal-Measures are met with in South Wales and in Devon & Cornwall.

As, however, we follow the line of the Artois-Mendip axis from east to west, it appears that higher and higher horizons are met with, and that deposition in Carboniferous times continued longer towards the west, than in the east. In the Pas de Calais, in Zone C of Prof. Zeiller's[4] classification, we meet with the Upper Transition Measures, and, as has been shown here, these also occur in Kent. Farther westwards, in Somerset, and in South Wales (omitting for the moment the Forest-of-Dean Coalfield, the flora of which I have not yet completely worked out), we find that, in addition to the Upper Transition Measures, a higher zone, that of

[1] Munier-Chalmas & A. de Lapparent (93^1) p. 871; see also (93^2) p. 450.
[2] Kidston (05).
[3] Zeiller (94^1) pp. 494 & 500.
[4] *Id.* (94^1) pp. 491 & 495.

the Upper Coal-Measures, is represented, which is not found to occur in France. In the British basins of the Artois-Mendip system, the Middle Coal-Measure zone is the sole representative of the true Westphalian, while the Transition Measures and the Upper Coal-Measures, although they may for convenience be retained as horizons within the Westphalian zone, appear to me to be an early and a late stage in the perfect transition between the floras of the Westphalian and the Stephanian. In the earlier (the Transition Measures) the number of Westphalian types is considerable, while the Stephanian are usually fewer; whereas in the Upper Coal-Measures, as Prof. Zeiller [1] pointed out many years ago, the Westphalian species are still abundant, although the Stephanian elements play a more important part in the flora. It will be interesting to see how far the theory of successive horizons met with in the Artois-Mendip system of coalfields (as yet provisional, in view of our scanty knowledge of the flora of many of the Southern British coalfields) may be confirmed by future observations. At present it would appear that we may be able to distinguish eventually a new Continental zone between the Westphalian and the Stephanian, forming a true transition between the two, and which will include, as upper and lower local horizons, our British Upper Coal-Measures and the Upper Transition Measures. But, before such an attempt can be made, it must be shown that such a Transition Series is found over wide areas in the Northern Hemisphere.

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[1] Zeiller, in Kidston (87) pp. 408–409.

G. M. Woodward del. et lith.

West, Newman imp.

CARBONIFEROUS PLANTS FROM KENT.

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EXPLANATION OF PLATE I.

[All the figured specimens have been kindly presented by Mr. Arthur Burr to the Sedgwick Museum, Cambridge (Carboniferous Plant Coll.).]

Fig. 1. *Annularia sphenophylloides* (Zenker). From the Waldershare Series at 1843 feet. No. 1914. $\times \frac{4}{3}$. (See p. 25.)

2. *Neuropteris rarinervis*, Bunb. From the Waldershare Series at 1762 feet. No. 1915. $\times 2$. (See p. 26.)

3. *Neuropteris obliqua* (Brongn.). From the Waldershare Series at 2402 feet. No. 1916. $\times \frac{4}{3}$. (See p. 26.)

4. *Odontopteris lindleyana*, Sternb. From the Waldershare Series at 1873 feet. No. 1917. $\times \frac{4}{3}$. (See p. 27.)

5. *Cardiocarpus acutus*, L. & H. From the Waldershare Series at 2425 feet. No. 1918. $\times 2$. (See p. 29.)

6. *Mariopteris muricata* (Schloth.) var. *nervosa* (Brongn.). From the Waldershare Series at 1830 feet. No. 1919. $\times \frac{5}{4}$. (See p. 28.)

7. *Neuropteris tenuifolia* (Schloth.). From the Waldershare Series at 1407 feet. No. 1920. $\times \frac{5}{4}$. (See p. 26.)

8. *Sphenopteris neuropteroides* (Boulay). From the Fredville Series at 1458 feet. No. 1921. $\times \frac{4}{3}$. (See p. 29.)

DISCUSSION.

The PRESIDENT congratulated the Author on his definite determination of the age of the Dover Coal-Measures. The absence of the Stephanian, which was in harmony with what was known of other British coalfields, seemed to suggest that in these islands the Armorican movements had already commenced at the close of the Westphalian Epoch. If so, additional time would be afforded for the extensive denudation indicated by the unconformable relation of the Permian to the Carboniferous. Great as this unconformity undoubtedly was, the strata that might be taken to represent it, in regions where sedimentation was continuous from the Carboniferous to the Permian, were by no means so thick as geologists might naturally have expected.

Prof. HULL said that he had listened with much interest to the Author's statement regarding the plant-remains of the concealed coalfield of Kent, and greatly admired the forms thrown on the screen. With regard to the relations of the coal-seams proved at Shakespeare's Cliff near Dover, and those recently discovered at Waldershare and Eythorn, he gathered that they were almost on the same geological horizon; and that, while the seams at Dover

were nearly horizontal, in consequence of being at the centre of the trough, those at the other places were in proximity to the north-eastern margin, where the dip was considerable, as shown by the specimens on the table, say about 15° to 20°. The speaker remarked, however, that, so far as he was aware, no very certain means had been invented for determining the direction of the dip by means of cores brought up from bore-holes; in the case of Waldershare, there were reasons for inferring that the dip must be in a south-westerly direction.

Mr. J. A. Thomson asked the Author at what heights above sea-level the various bore-holes were started.

The Rev. H. H. Winwood alluded to the fine assemblage of fossils collected by Mr. McMurtrie from the Radstock Coalfield, the measures in which were commonly divided into Upper and Lower Coal-Measures by a vast mass of Pennant Sandstone, and asked the Author to which horizon he would refer them. The fossils had been examined some years ago by Dr. Kidston.

The Author, in reply to Prof. Hull, said that the Pas-de-Calais Coalfield appeared to offer the closest analogy to that in Kent, for only the highest beds there represented, forming the zone of the Charbons Gras (which was the equivalent of the British Transition Series), were of economic importance; whereas, in the Pennine System, a lower horizon, the Middle Coal-Measures, was the most important coal-bearing zone.

In reply to questions as to the amount of the dip, and the depth of the Coal-Measures at Waldershare, the Author stated that, as he had not had the oversight of the actual borings, he could add nothing to what Prof. Boyd Dawkins had already stated on those points. With regard to the question as to the horizon of the Radstock and Farrington Series of the Somerset Coalfield, Dr. Kidston had shown, more than twenty years ago, that both these series belonged to the Upper Coal-Measures.

3. *The* Relations *of the* Nubian Sandstone *and the* Crystalline Rocks *south of the* Oasis *of* Kharga (Egypt). By H. J. Llewellyn Beadnell, Assoc.Inst.M.M., F.G.S., F.R.G.S., late of the Geological Survey of Egypt. (Read November 4th, 1908.)

[Plate II—Map.]

In the geological study of a country there is nothing of more importance than the mutual relations of the different rock-groups of which it is made up, and yet in Egypt it is perhaps more especially in regard to those relationships that our views have had from time to time to be materially altered. In particular, I may instance the relationships of the Eocene and Cretaceous Systems in different parts of the country, notably at Abu Roâsh, in the Eastern Desert, and in the Oases. The object of the present paper is to raise the question of the relation of the granites and associated crystalline rocks to the overlying sedimentary formations, a relationship of fundamental importance, and to put on record some observations bearing on the subject made during a brief examination of the country to the south of the Oasis of Kharga, undertaken with the primary object of eliciting certain information regarding the water-supply of that oasis. These observations appear to me to afford strong evidence that in this district the granites, in their present position at least, are younger than the overlying members of the Cretaceous Series.

The Crystalline Rocks south of the Oasis of Kharga.

That a solitary exposure of igneous rock exists at Jebel Abu Bayan, in the Libyan Desert south of the Oasis of Kharga, has long been known. Capt. Lyons, with reference to this locality, wrote[1]:

> 'The rock is a coarse-grained hornblendic granite, with large crystals of pink orthoclase, and is apparently identical with that described by Prof. Bonney.[2] The hill also contains dykes of a fine-grained granitic rock, and some of a diorite, as well as one of a fine-grained basalt.'

The relations to the surrounding sedimentaries are not touched upon.

That other granitic bosses occurred in this desert, I have long suspected, from reports of Bedawīn tribesmen who traverse this country on their way to and from El Atrûn (Bir-el-Sultan). Indeed, this was partly confirmed by a prospector whom I sent in 1906 to

[1] 'On the Stratigraphy & Physiography of the Libyan Desert of Egypt' Quart. Journ. Geol. Soc. vol. l (1894) p. 532.

[2] 'Note on the Microscopic Structure of some Rocks from the Neighbourhood of Assouan, collected by Sir J. W. Dawson' Geol. Mag. dec. 3, vol. iii (1886) pp. 103–107.

examine the district, and report on the nature of the junction of the granites with the sedimentary rocks; no information of value on this latter point was, however, forthcoming. Although my preparations had been made for many months, it was only quite recently that I found time to pay a hurried visit to this part of the desert, which curiously enough had received the attention of my former colleague, Dr. Hume, a few weeks previously. Hume informed me that he had found a number of granite-exposures, and that they had proved one of the most interesting features of his trip. I await with great interest the publication of his results, as it is more than probable that we both visited some of the same exposures.[1]

The southern limit of my journey was lat. 24° N., or a little south of the latitude of Aswân. The area examined and mapped (south of the most outlying of the oasis-wells) amounts to 2500 square kilometres, the actual distance traversed as the crow flies being about 225 kilometres, and the time occupied six days. One day of comparative inaction was spent at El Nakhail; but, as trotting camels were used, I was able to visit most, if not all, of the prominent hills on the plain, as well as a number of points on the scarps to the east. The area was surveyed by plane-table triangulation extended from accurately fixed points in the Oasis, and the position of El Nakhail, the southernmost point reached, is I believe very little in error. The time of year was the latter part of May, and coincided with a spell of very trying weather. I mention these details, as showing that circumstances were not favourable for that leisurely examination and detailed mapping to which the area, on account of its exceptional interest, is entitled.

Eight actual exposures of crystalline rocks were met with, distant from the village of Beris in the south of the Oasis, as follows:—

[1] Since writing the above I have been in correspondence with Dr. Hume, who in a letter, under date June 7th 1908, writes:—'With regard to your statement about the granites, I am sorry to say that we are not in agreement. I find that the rocks of igneous nature are of every variety common to the Red-Sea Hills, and even include metamorphics such as gneisses and schists, nor do I see any evidence of metamorphism in the sandstone. You have no doubt been impressed by the steep dipping of the sandstones round the granite-ridges, but my explanation is acute folding passing into faults, accompanied by differential movements between masses of different consistency.'

As will be seen from a later paragraph, we are in agreement as regards the similarity of the crystalline rocks in this part of the Western Desert and those of the Red-Sea Hills. Until Dr. Hume's results are published, I must refrain from discussing the question whether the explanation of folding is adequate to account for the observed facts. It is, in any case, satisfactory to find that we are both of opinion that the present positions and relations of the crystalline and sedimentary rocks are not what they were at the time of the deposition of the latter. [Since these lines were written, the concluding portion of Dr. Hume's memoir on the South-Western Desert of Egypt, with map, has been published in the 'Cairo Scientific Journal' vol. ii, no. 24 (September, 1908) pp. 314–25.]

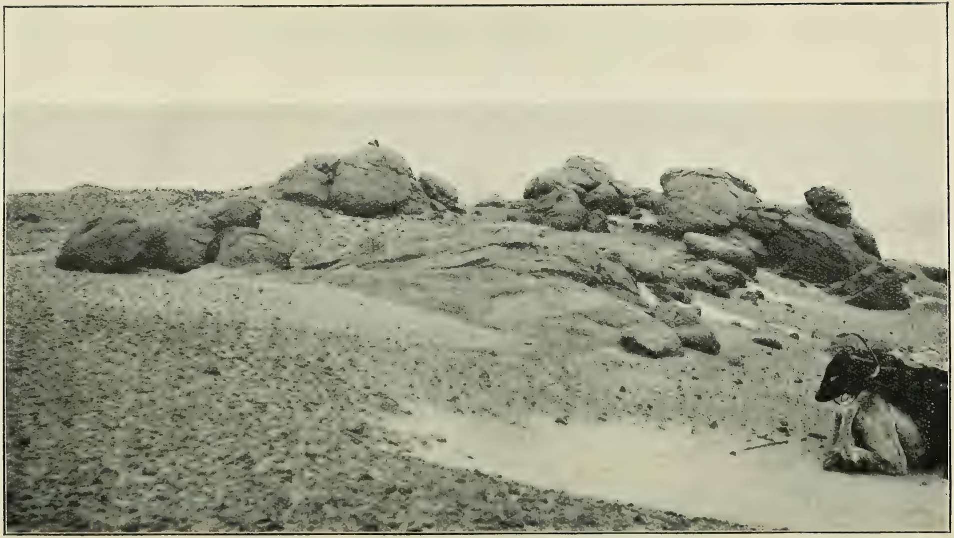
	Distance from Beris.	*Bearing from Beris.*
A	$35\frac{1}{4}$ kilometres.	180°
B	$47\frac{1}{2}$,,	181°
C	48 ,,	184° 30′
D	50 ,,	188°
E	$61\frac{1}{2}$,,	181° 30′
F	$48\frac{1}{2}$,,	165° 30′
G	$35\frac{1}{2}$,,	161°
H	$36\frac{1}{2}$,,	153°

A glance at the accompanying map (Pl. II) will show that these granite-bosses, which vary from 100 metres to 3 kilometres in length, lie along well-marked east-and-west lines; although isolated, the exposures A, G, and H may be regarded as belonging to one and the same crystalline ridge; so also F, B, C, and D must be looked upon as portions of a second and parallel ridge. The small knob E, although not obviously connected, is probably related to others in the sand-covered country stretching to the west and south-west.

A.—Although no one of the bosses corresponds with the position assigned to Jebel Abu Bayan on the Egyptian Survey-maps, it is probably this exposure that is referred to and was visited by Capt. Lyons. The name appears to be applied indiscriminately to this and to some of the hills farther south; but I propose, in order to avoid confusion, to restrict it to this one alone. Approached from the north, Jebel Abu Bayan appears as a dark bun-shaped eminence rising out of the dunes. As a matter of fact, it is situated in an open space quite clear of sand, the ground rising to it from all sides, except possibly on the west. It is an unpicturesque-looking hill, and from a distance shows few of the characteristics of an igneous boss, being indeed less conspicuous than many of the ordinary sandstone-capped hills of this desert. Both coarse- and fine-grained granites occur, although the latter are most in evidence owing to their superior hardness and powers of resistance to weathering. Various dyke-rocks are also to be seen.

On three sides of the hill the junction with the sedimentary rocks is invisible, but at the western end coarse pink and yellowish false-bedded ferruginous sandstones are met with, dipping away from the granites at a low angle to the north-west. Some of the sandstone-beds are very coarse, containing numerous small subangular pebbles of quartz. The actual junction is observable at one point, the eastern end of the sandstone-ridge immediately west of the igneous slope. There the sandstone appears to pass down into a decomposed granite, reddish in colour, friable, and full of pieces of quartz and powdered felspar. The impression left on my mind by this junction would have been in favour of the sandstones having been deposited on the granite, if it had not been for the rather marked tilting of the former; altogether, I did not feel justified in drawing any definite conclusion from the evidence met with.

Fig. 1.—*Summit of granite-boss, $47\frac{1}{2}$ kilometres south of Beris (Kharga Oasis).*



H. J. L. Beadnell photogr.

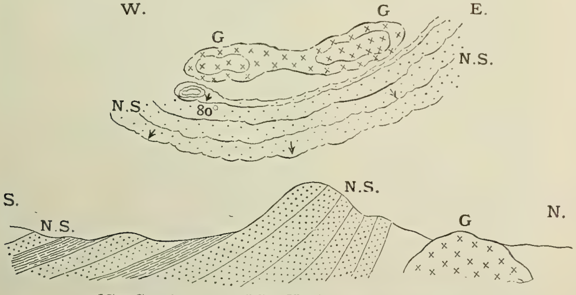
B.—The great mass of this hill is a coarse-grained pink hornblende-granite, with dykes of harder felsitic rocks. The summit of the boss is covered with large blocks showing characteristic granite-weathering (fig. 1, p. 44). The actual junction with the sedimentary rocks was not observed; but at the western end of the hill, in close proximity to the igneous rocks, brown, black, yellow, and purple ferruginous grits and sandstones were met with, dipping at 30° west-south-westwards, directly away from the crystalline rocks.

The marked and local tilting of the sedimentaries in the immediate neighbourhood of the igneous rocks appeared to me most suggestive, as obviously the inclination of the beds was far too high to be explicable as being a 'dip of deposition' on a shelving shore-line. It was the difficulty of explaining the appearances here, other than on the supposition that the granites were intrusive, which first made the latter idea appear possible.

C & D.—These are small isolated exposures of pink granite, to the west of the large boss just described. The junction with the surrounding sedimentaries is not visible at either place. Some 12 kilometres farther west lies a range of prominent sandstone-hills; and it was noticeable, even at that distance, that in one locality the beds showed marked tilting. The position of the disturbed beds, on being plotted, proved to be exactly on a line drawn though B, C, and D, and one is tempted to connect it with an underground extension of the crystalline ridge. The point is at least worthy of investigation.

E.—The actual exposure at this place is very small, but the facts observable are of the highest importance. The crystalline

Fig. 2.—*Plan and section of Exposure E, 61½ kilometres south of Beris (Kharga Oasis).*



[G = Granite, etc. N.S. = Nubian Sandstone Series.]

rock is medium-grained pink and grey granite, associated with black, close-grained basic rocks. The sedimentary deposits are plainly

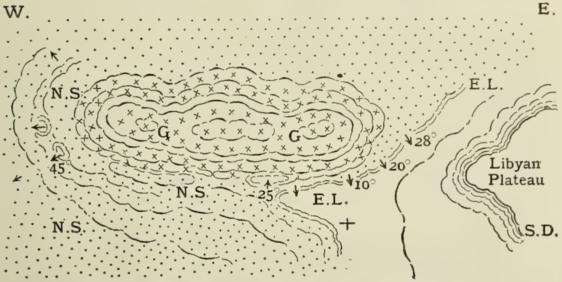
Fig. 3.—*Junction of Nubian Sandstone (forming the eminence) and crystalline rocks (in the foreground) at Exposure E, $61\frac{1}{2}$ kilometres south of Beris (Kharga Oasis).*

H. J. L. Beadnell photogr.

exposed on the south side: the dip, which is always directly away from the granites, increasing rapidly from a few degrees until it amounts to as much as 80° in the beds immediately alongside the igneous rocks. Moreover, the sedimentary beds become most markedly changed as the igneous rocks are approached; they assume bright hues, and the sandstones become so hard and silicified that only with the greatest difficulty can fragments be detached with a hammer. To my mind the beds show undoubted signs of contact-metamorphism, and there seems no escape from the conclusion that the sedimentaries here have been thrust up and metamorphosed by the intrusion of the granites. The outcrops of the tilted beds follow the crystalline exposure in a curve, which alone would appear to negative any supposition that their disturbed state could be accounted for by faulting. The distance from the actual granite to the beds tilted at 80° is not more than 10 paces; the accompanying figures (2 & 3, pp. 45 & 46) show the general appearance of things at this interesting spot.

F.—This is a big boss of granite forming a hill about a couple of kilometres long, situated immediately adjacent to the high escarpment—the continuation of the eastern wall of the Oasis—formed of the fossiliferous shales and limestones belonging to the Senonian and Danian divisions of the Upper Cretaceous. At the western end of the hill, brown and purple sandstones are seen dipping steadily

Fig. 4.—*Plan of Exposure F, 48 kilometres south-south-east of Beris (Kharga Oasis).*



[G=Granites, etc. N.S.=Nubian Sandstone Series. E.L.=*Exogyra*-Limestones. S.D.=Senonian–Danian Series.]

away from the crystalline rocks, the inclination reaching a maximum of 45°. The sandstones may be observed in close proximity to the igneous rocks, although the actual point of contact is obscured; they are fissured and shattered in the most remarkable way. Near the junction, the granite itself is curiously foliated and broken up; I observed no signs of an eroded surface.

If confirmatory evidence of the intrusion of the granites were required, it is I think indubitably furnished at the south-eastern end of the hill, for here the limestone-beds of the *Exogyra*-Series, which overlies the Nubian Sandstone, are themselves thrust up and dip away from the igneous boss at inclinations of 10°, 20°, and 28° to the south. In one spot, on the south side, the limestones dip steeply against the granite at 25° north (see fig. 4, p. 47). Veins of quartz are noticeable in the granites, which do not differ in any important respect from those already described.

G & H.—These are the most extensive exposures met with. The two hills together have a length of 8 kilometres, and form a prominent feature of the landscape to the south of the village of Dush, from which they are distant only 22 kilometres. Like the boss just described, H lies close against the Cretaceous escarpment.

The foot-hills at the western extremity of G consist of beds of coarse brown grit, dipping steadily away from the crystalline boss at 25°. The actual contact of the sandstone with the igneous rock is clearly exposed: the granite has a dull grey appearance (perhaps due to kaolinization of the felspars); its actual junction with the sandstone is wavy, and well seen where the igneous rock has been weathered away, leaving the tilted sandstones overhanging. There is a good deal of quartz at and about the actual junction, but more in the nature of angular lumps of irregular shape filling cavities than waterworn pebbles, although there are small pebbles in the sandstones themselves. I saw nothing, in fact, to favour the view that the granite was in its present position before the deposition of the sandstones.

At the south-eastern corner of G, highly-tilted shelly limestones were again observed, and across the space intervening between the two hills more disturbed sandstones were met with. Again, at the eastern end of H a mass of sandstone and altered shale occurs dipping off the igneous boss at an angle of 30° south-eastwards. A pebble-bed of white quartz is conspicuous here in the sandstones, at least 100 feet above the beds that are in contact with the igneous rocks.

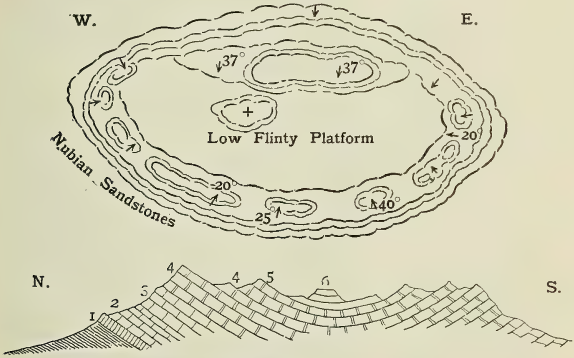
This concludes my remarks on the igneous exposures themselves, which I have described in the order in which they were met with and examined in the field. I venture to think that the disturbed state of the strata in the immediate neighbourhood of the igneous rocks, the marked alteration which they have in many cases undergone, as well as the nature of the actual contact where the latter is visible, can only be satisfactorily accounted for on the supposition that the granites have been intruded in a viscous state against and into the sedimentary rocks. The lack of gravels or conglomerates between the ordinary sandstones and the crystalline rocks, and the entire absence of gently inclined, annularly contoured, overlapping sandstones, such as one would expect to meet with if the sedimentaries had been deposited on the flanks of a subsiding ridge or island, appear to confirm this view.

Hills of Folded Eocene and Cretaceous Strata.

I cannot omit mention here of two very remarkable eminences, consisting of sharply-folded strata belonging to both the Cretaceous and the Eocene Systems, which from their position are evidently closely connected with the crystalline ridge formed of the exposures F, B, C, and D. These folded hills are marked J and K on the map (Pl. II).

At J there are several hundred feet of Cretaceous and Eocene beds involved, beginning with the *Exogyra*-Series at the base; above this come the chalky limestones containing simple corals, of Senonian-Danian age. These pass up into *Operculina*-Limestones marking the base of the Eocene, while still higher lies a thick series

Fig. 5.—*Plan and section of centroclinal fold, 47 kilometres south-south-west of Beris (Kharga Oasis).*



Lower Eocene.
- 6 = Limestones, with flint and chert.
- 5 = Shelly limestones.
- 4 = Nummulitic limestones.
- 3 = *Operculina*-Limestones.

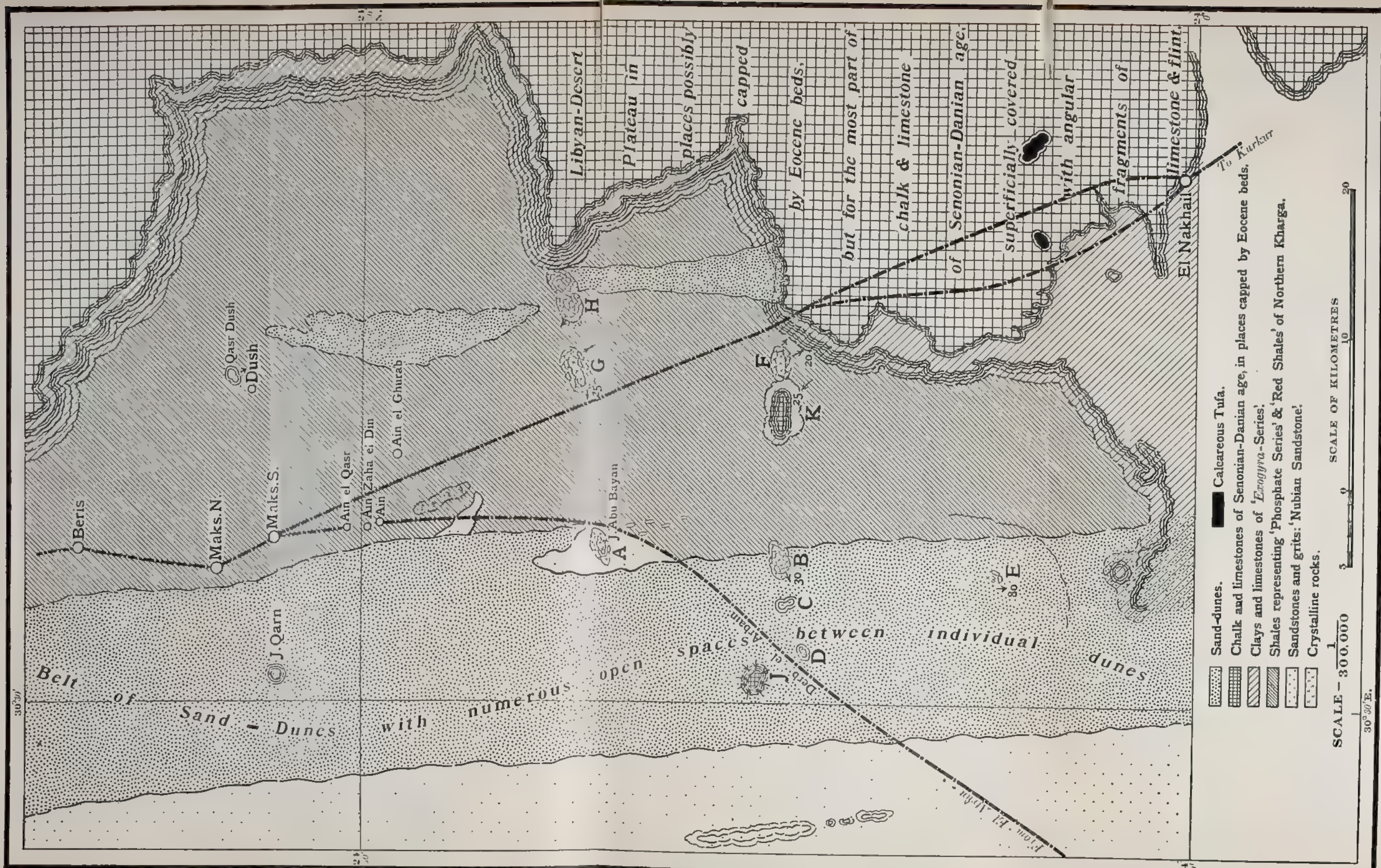
Upper Cretaceous.
- 2 = Chalky limestones with simple corals.
- 1 = *Exogyra*-Limestones.

of Nummulitic limestones, above which are the highest and youngest beds of all, limestones with an abundance of chert and flint. This great mass of limestone, very hard and crystalline, is bent into an elliptical centroclinal fold, with dips up to 40°. The appearance of the top of the hill-mass—a ring of highly inclined rocks enclosing a more or less level platform—is remarkable (figs. 5 & 6).

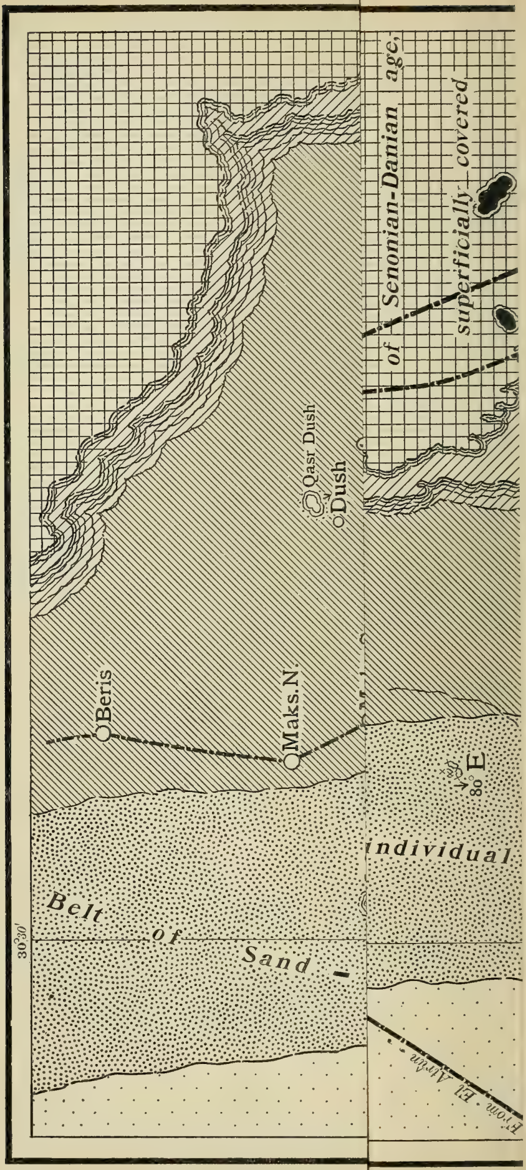
The other hill, K, is a rather longer and narrower fold lying immediately west of the granite-boss F; the disturbed strata here

Fig. 6.—*Part of the centroclinal fold, 47 kilometres south-south-west of Beris (Kharga Oasis).* *(See p. 49.)*

H. J. L. Beadnell photogr.



Geological Map of the Libyan Desert south of the Oasis of Kharga, showing the Bosses of Igneous Rock.


of Senonian-Danian age,
superficially covered
Qasr Dush
Dush
Beris
Maks.N.
80° E
individual
Belt of Sand
30°30'

dip from the north and south sides into a narrow trough, forming a syncline with angles up to 45°. Both Eocene and Cretaceous strata are again involved, though the former, owing to their crystalline and crushed nature, are not so obvious as in the fold J just described, 18 kilometres farther west. Drawn-out and distorted nummulites are, however, quite common in some of the upper beds.

The importance of these hills of highly disturbed strata lies in the fact, that if connected with the intrusion of the granites—which from their position appears almost certainly is the case,—the date of the latter would be later than the Lower Eocene.

Similarity of Crystalline Rocks in the Western and Eastern Deserts.

The crystalline rocks forming the bosses just described do not appear to differ essentially from those of the Cataracts and the Eastern Desert. As already mentioned, they form two parallel ridges trending east and west; and as they are situated on almost the same latitude, the natural inference is that both they and the rocks of the First Cataract at Aswân are of the same age, representing different portions of the same great underground ridge, the latter being exposed on the comparatively low ground of the Nile Valley and on the floor of the Oasis, but hidden by the immense thickness of the sedimentary formations forming the intervening plateau-massif.

This view, however, at once brings us face to face with the difficulty that, whereas in the Oasis the granite appears to have intruded into the sedimentaries, at the Cataracts and in the Eastern Desert they are, according to the authors who have dealt with the subject, unquestionably of far greater age than the Nubian Sandstone.

The general conclusions at which I have arrived are that there seems reason to believe that the crystalline rocks of Egypt are of many different ages, and that at various periods there have been upward movements and intrusions from the underlying magma, with a tendency for successive consolidations to assume somewhat marked similarities. The Nubian Sandstone appears to have been unconformably deposited, partly on pre-existing sedimentary formations, and partly on the planed-down surfaces of still older crystalline and metamorphic rocks. Subsequently, at one or more periods, they and the sedimentary and crystalline rocks on which they lie, were in some regions invaded by outbursts from the underlying magma, the intrusions being probably connected with the elevation of the mountainous regions on the east side of the Nile.

EXPLANATION OF PLATE II.

Geological map of the Libyan Desert south of the Oasis of Kharga, showing the bosses of igneous rock, on the scale of $\frac{1}{300,000}$, or about 5 miles to the inch.

Discussion.

The President remarked that the Author's observations, though of great interest, scarcely sustained his contention. Disturbances in dip might be due to various kinds of movement. No conclusion could be drawn from the absence of granite-pebbles in the overlying sediments; for, in isolated exposures of obvious unconformities, pebbles derived from the underlying rock were not uncommonly absent from the unconformable covering. The evidence of contact-metamorphism was very indefinite.

Prof. Hull, while recognizing the zeal of the Author and the difficulties of observation in the Egyptian desert, was unable to accept his conclusions regarding the relations of the Nubian Sandstone to the granitic and crystalline rocks, either of Egypt or of Sinai. The Author had not adduced a single instance of intrusion of the granite into the sandstone, or of the former overlying the latter at the place of contact. From his own observations at Aswân, and also in Arabia Petræa and the Sinaitic Peninsula, it was quite clear to him, as it had been to the observers whom the Author had quoted—that the crystalline rocks were immensely older than the sandstone-formations of those regions; and he believed that the former had been rightly referred by Fraas in 'Aus dem Orient' to the Archæan Era. The Author did not seem to have been aware that, in the Sinaitic Peninsula, there were two sandstone-formations, separated one from the other by the Carboniferous Limestone, discovered some years ago by Mr. H. Bauerman. This limestone-plateau at Wady Nash had been visited by the speaker, during his passage through the country with the members of the Expedition sent out in 1883–84 by the Palestine Exploration Committee, and a collection of fossils was brought home, the organisms being identified as those of the Carboniferous Limestone. This formation rests upon a lower sandstone-formation, reddish or variegated, and often conglomeratic, laid down over an uneven floor of the crystalline rocks; and, being altogether older than the Nubian Sandstone, it had been named by the speaker 'The Desert Sandstone.' He begged to refer the Author to the Memoir drawn up for the Palestine Exploration Fund on 'The Physical Geology & Geography of Arabia Petræa' (1886), which he did not appear to have seen, although it had been quoted in the reports of the Geological Survey of Sinai under Capt. Lyons. Throughout the whole of that region there was no case of these old crystalline rocks, or of the dykes (which were numerous), invading either of the sandstone-formations.

Mr. Hudleston said that he felt a certain amount of hesitation in intervening in the discussion, as he had never visited the district described. It was perfectly clear, however, that the Author was at variance with the whole literature of the subject, and he (the speaker) was very much inclined to be of the same opinion as Prof. Hull, in regard to the Author's mistaken view of the relationship of the crystalline rocks to the Nubian Sandstone. There was

no evidence that the dykes ever pierced that sandstone. The conclusions advanced by Sir J. William Dawson, in his 'Modern Science in Bible Lands' (1888), had been fully justified by the work of the surveyors who acted under Capt. Lyons. The whole region must have been upraised since Cretaceous times, and hence it was not surprising to find a certain amount of confusion at the contact between the Nubian Sandstone and the crystalline rocks, confusion which the Author had apparently taken for intrusion.

Dr. Teall said that he had spent a few days at Aswân, and had examined junctions of the Nubian Sandstone with the underlying crystalline rocks between Aswân and Philæ. He had with him at the time of his visit the admirable map and memoir issued by the Egyptian Geological Survey, in which Dr. Ball had recorded the result of his detailed work in the region, and he could confirm the accuracy of Dr. Ball's description of the relation between the two groups of rocks. He (the speaker) had not a shadow of doubt that the Nubian Sandstone had there been deposited upon a crystalline complex, and he did not believe that there was a shred of evidence in that region of the intrusion of any granitic rock into the Nubian Sandstone. But the important part of the Author's paper was that in which he recorded original observations in a comparatively unknown region: such observations were always welcome. The high dips in the sedimentary rocks, on which the Author laid great stress as evidence of intrusion of the granite, might be, and probably were, due to earth-movements similar to those that the Author had so well described at Abu Roâsh, in which also Cretaceous rocks were involved. Contact-metamorphism had been mentioned, and, if it were positively proved, the Author's case would be made out so far as the special district was concerned; but, even then, the result would not affect the well-established conclusions arrived at by previous observers in the region of the First Cataract and elsewhere.

The Author, in replying, remarked that he was well aware that the sandstones described as Nubian were in some parts of the country of considerably earlier age than Upper Cretaceous. There seemed little doubt, however, that in the area described the sandstones were of the same age as those in the northern part of the Oasis, that was, Campanian.

He wished to point out that he himself had for many years (and he had been actively engaged in geological work in Egypt for 12 years) accepted the view still held by his former Survey colleagues, that the granites were in all cases older than the Nubian Sandstones; and that it was not until after he had visited the district in question, and carefully weighed the whole of the published evidence relating to other parts of the country, that he found himself forced to dissent from the commonly-held view and admit that some of the cases of intrusion cited by Schweinfurth, Russegger, and other early observers, might not after all have been incorrect. He did not, however, wish to insist, as seemed to be assumed by Prof. Hull and Mr. Hudleston, that the granites in all parts of the country were intrusive—he had indeed definitely stated the

contrary; but, on the strength of the occurrences in the Libyan Desert, he asked for a reconsideration of the numerous published statements that the granites were never intrusive into the sandstones.

With regard to the question of contact-changes, it was because he felt that this required more careful consideration, both in the field and in the laboratory, than he had been able to give to it, that he had not laid greater stress on the point. There were, however, undoubted changes in the sedimentaries in the immediate neighbourhood of the granitic bosses, the sandstones being discoloured, indurated, and silicified; and he believed that the marked changes noticeable in some of the shales might be due to baking.

Finally, he wished to thank Dr. Teall for referring to his work at Abu Roâsh, and would like to add that, not only there, but in the Eastern Desert and in the Oases, his detailed work had necessitated entire revision of views at least as firmly held as the one with regard to which he now asked for careful reconsideration.

4. *On some* Intrusive Rocks *in the* Neighbourhood *of* Eskdale (Cumberland). By Arthur Richard Dwerryhouse, D.Sc., F.G.S. (Read November 18th, 1908.)

[Plate III—Microscope-sections.]

I. Introduction.

Chief amongst the group of intrusive rocks which it is my purpose to describe is the granite of Eskdale and Wasdale Head, which possesses petrological characters of peculiar theoretical interest; but I shall also deal with certain minor intrusions near the foot of Peers Gill in Upper Wasdale, and with several groups of dykes which have been usually thought to be associated with the Eskdale Granite, but appear to me to have had a separate origin at a period remote from that of the intrusion of the granite.

II. The Eskdale Granite.

The granite comes to the surface in two exposures. The larger and more southerly of these occupies an extensive tract of country in Eskdale and Mitredale, and extends southwards as far as Bootle Fell, while it reaches to within a mile of the sea in the neighbourhood of Ravenglass.

The smaller outcrop lies in the floor of Upper Wasdale and extends from Down-in-the-Dale, beneath the hotel at Wasdale Head, and up the valley to about half a mile above Burnthwaite Farm. The larger outcrop has a total length of some 12 miles and a breadth of 4 at its widest part, while the smaller mass measures about 1 mile in length by half a mile in breadth, and is roughly elliptical in form.

The rock is mentioned by Clifton Ward in a paper entitled 'The Granitic, Granitoid, & Associated Metamorphic Rocks of the Lake District,'[1] and also in the Geological Survey memoir on the district.[2] In the former paper Ward describes the granite as being the ultimate product of the metamorphism of the rocks of the Borrowdale Volcanic Series. This view is, of course, unsupported by modern work, and indeed the composition of the rock itself is inconsistent with such a mode of origin.

[1] Quart. Journ. Geol. Soc. vol. xxxi (1875) pp. 568–602 & vol. xxxii (1876) pp. 1–34.

[2] 'The Geology of the Northern Part of the English Lake District' Mem. Geol. Surv. 1876.

Reference is also made to the Eskdale Granite by Mr. Harker,[1] who classes it with the biotite-granites, and by Dr. Teall in his 'British Petrography' 1888, pp. 322–23, the latter describing the rock as follows :—

'The ferromagnesian constituent (generally dark mica) plays a very subordinate part in the composition of the rock . . . . . . the quartz is frequently idiomorphic with respect to the felspar, or else the two minerals exhibit a tendency to micropegmatitic structure. Plagioclase is sparingly represented, and the quartz is sometimes seen to be idiomorphic with respect to it; a somewhat unusual feature.'

The specimen thus described, although it can be accurately matched from at least two parts of the outcrop, can hardly be considered typical of the Eskdale Granite, which is essentially a muscovite-bearing rock and in which a felspar consisting of an intergrowth of orthoclase and oligoclase is extremely common. The numerous varieties of this granite will be presently described.

Field-Relations of the Granite.

The granite is intrusive in the lavas and ashes of the Borrowdale Series, and its line of junction with these rocks is well seen at intervals along its north-western, northern, south-eastern, and eastern margins; but to the westward both the Borrowdale rocks and the granite are covered unconformably by the Trias (St. Bees Sandstone).

For a distance of about half a mile, from the foot of Wastwater to Easthwaite Farm, the granite is in contact with the Buttermere and Ennerdale Granophyre recently described by Mr. R. H. Rastall.[2] From the foot of Wastwater the boundary runs due south up the steep slope by Pens End on to the shoulder of Whin Rigg, the junction being for some distance a faulted one, and the fault-plane being occupied by a vein of ironstone. The line of fault cannot, however, be far from the edge of the intrusion, as the natural boundary comes in on the crest of the hill, and in several places on the slope the fine-grained marginal varieties of the granite, which will be more fully described hereafter, are to be seen.

The floor of Mitredale is occupied by the granite, and in Robin Gill, a tributary of the Mite, the junction of the granite and the Borrowdale rocks is seen dipping at a low angle northwards. The granite becomes increasingly finer in texture as the margin is approached, and undergoes at the same time a considerable change in chemical composition. The Borrowdale rocks are much altered, and in some places approach the condition of a mica-schist.

From Mitredale the line of junction passes along Black Gill over White Moss to Brown Band, and turns northwards by Acre Hows and Eskdale Moor to the shores of Burnmoor Tarn. It then crosses Hardrigg Gill at 1100 feet above O.D., the junction being visible

[1] 'Petrology for Students' 3rd ed. (1902) p. 37.
[2] Quart. Journ. Geol. Soc. vol. lxii (1906) pp. 253–73.

in the small gorge at the head of the cascade, about 10 yards below the point where a small tributary joins the stream on its left bank. Close to the junction the granite is white with a greenish tinge, is extremely fine-grained, and contains 96·16 per cent. of silica. Some 10 yards farther from the margin it assumes a pink colour, and is similar in texture to the finer specimens from Robin Gill. Specimens of the actual junction were collected, and a junction-breccia, consisting of fragments of Borrowdale lava in a granite-matrix, occurred as boulders in the bed of the stream.

In Oliver Gill the junction occurs at about 1150 feet, the actual contact being obscured by boulders. The granite and the Borrowdale rocks may, however, be traced to within 15 yards of each other, the former showing marginal features. From Oliver Gill the boundary rises considerably, and on Blaebury How is at a height of 1350 feet. The granite is fine-grained and white; the fine-grained pink variety comes in farther from the margin and extends down to 1150 feet, gradually passing into the normal granite at lower levels.

The edge of the granite now passes along the flanks of Great How and gradually assumes a lower level, until at Whinscales Sheepfold, near the head of Brockshaw Beck, it is at a height of 1200 feet. At this point the junction dips at an angle of about 45° eastwards. The marginal zone is unusually narrow at this point, the rock in contact with the granite being a bedded ash. There is a well-marked junction-breccia here, the fragments of Borrowdale Ash between the granite-veins being remarkably angular and showing no signs of absorption (100 & 101).[1]

Stony Tarn lies in a hollow in the Borrowdale rocks, the granite-boundary sweeping round to the south-west of it, and being cut off by a fault at Peelplace Noddle. Between Peelplace Noddle and the River Esk the country is much faulted, the faults carrying some hæmatite, being marked on the Survey-maps as metalliferous veins, and rendering the boundary somewhat intricate.

The most noteworthy features in this area are the junction-breccia, which is developed on a large scale near Whin Crag (131 & 132), and the junction near the confluence of Scale Gill with the Esk. At the latter place the granite is somewhat coarse to within a few feet of the margin, and consists of quartz and felspar, the quartz-masses in some cases attaining several inches in diameter. Close to the margin it becomes finer in texture, and is bounded by a layer of almost pure quartz (108): this is in contact with the Borrowdales, which are much altered (see p. 68). The junction dips at a high though variable angle south-eastwards.

The boundary passes thence by Whahouse Bridge, and crosses to the southern (left) bank of the Esk, but is not well seen until Force Gill is reached, where it is at 450 feet above sea-level, thus having fallen some 900 feet from its highest point on Blaeberry How.

[1] These numerals within parentheses indicate, throughout the paper, the numbers of the localities on the Author's MS. maps and of the corresponding rock-specimens and microscopic slides, all deposited in the Museum of the Geological Department of the University of Leeds.

The actual contact in Force Gill is obscured by loose blocks which, however, include masses of the marginal varieties, from which it is assumed that the junction is a normal one and not faulted. There are in this neighbourhood many faults usually bearing ironstone, and numerous old drifts where this has been worked.

The line then passes by Low Ground to the eastern end of Devoke Water, and thence for about 2 miles in a westerly direction, being faulted along this section. It then turns sharply southwards and runs along the western flanks of Birkby Fell, Knott, Stainton Fell, Wabberthwaite Fell, Corney Fell, and Prior Park, to the head of Kinmont Beck, being obscured by Glacial deposits along much of the distance. It then bends to the west, and runs nearly parallel to the road as far as Hinning House near Bootle.

At Hinning House the boundary turns northwards and abruptly changes its character, the granite being overlain by the St. Bees Sandstone on the west, and continues to the north by Wabberthwaite to the neighbourhood of Ravenglass, where in the park of Muncaster Castle the Borrowdale rocks again emerge from beneath their covering of Trias and appear in contact with the granite.

From Ravenglass the junction may be roughly located and traced by Miteside, Irton Hall, and Mecklin Park to the foot of Wastwater, but is much obscured by drift and alluvium.

Junction with the Ennerdale Granophyre.

As already stated (p. 56) the granite comes into contact with the Ennerdale Granophyre near Easthwaite Farm. The contact is some 2000 feet in length, and extends from the foot of Wastwater to the neighbourhood of Easthwaite.

In no place could I see the actual junction, nor did I collect any junction-specimens from the loose boulders which cover the ground. A mixture of scree of a very coarse type, with Glacial deposits and torrent-gravels, the whole being covered in summer by a dense growth of bracken, renders the investigation of the boundary extremely difficult. I was, however, able to localize the line of junction within about 30 yards. At their nearest exposures the granophyre was normal in type, but the granite showed marginal features.

Both the rocks being acid in composition and unlikely, therefore, to show any marked results of thermal metamorphism, it is impossible at present to say which rock is the older; while the fact that the granite shows marginal features near the junction is consistent with either of the following views, namely:—

(*a*) That the granite was intruded into the Borrowdale rocks, which already contained the granophyre in a solid condition.

(*b*) That the granophyre was the later intrusion and that it came into contact with, but did not invade, the granite.

The granophyre is, as a rule, much fresher than the granite, and

this fact may perhaps, considering that the two rocks are of somewhat similar composition and similarly circumstanced as regards exposure, be taken as indicating that the granophyre is the newer rock. There is, however, at present no direct evidence as to the relative ages of the two intrusions, and I fear that this could not be gained without somewhat extensive excavations.

The Upper Surface of the Granite.

It is a fortunate circumstance that the whole of the covering of Borrowdale rocks has not been denuded from the granite, and the outliers on the summits of Blaetarn Hill and Great Barrow provide a means of determining the form of the upper surface of the intrusion. The granite shows marginal characters in both these cases, the hills being capped by Borrowdale rocks. At Great Barrow the outlier is faulted on the eastern side, and the Borrowdale rocks dip south-eastwards at an angle of 20°.

The relations of these outliers to the granite and to the general mass of the Borrowdale rocks will be made clear by a reference to the sections (figs. 1 & 2, p. 60), which are drawn to true scale.

It is interesting to note that on the crest of the granite-mass the Borrowdales are frequently reduced to a state of breccia, the interstices between the angular blocks of the lava and ash being filled by a rock identical with the marginal phase of the granite. This points to the intrusion having produced a disruptive effect along its highest part. This breccia is not seen along the flanks of the granite, although even here the volcanic rocks are penetrated for many feet by small veins of granitoid matter.

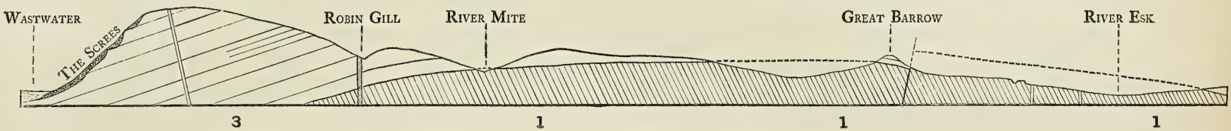
It will be noticed, on reference to the published 6-inch maps of the Geological Survey, that the Borrowdale rocks dip away from the axis of the granite-mass as though they had been elevated into a dome by its intrusion. Further evidence of the laccolitic nature of the intrusion is to be found in the fact that the granite becomes increasingly acid as its margin is approached, in some instances approximating in composition to pure quartz. The rocks into which the granite has been intruded are in every case of intermediate composition, consisting of andesitic lavas, ashes, and breccias; and, if marginal absorption of the surrounding rocks had taken place, even to a slight extent, one would have expected a higher proportion of the basic matter in the marginal varieties than in the normal granite more remote from the edge, whereas the opposite will be shown to be the case.

The junction-specimens which have been collected and those which have been examined in the field, show a clean-cut line of demarcation between the intrusive quartz-rock (marginal granite) and the Borrowdale rocks; and, even when examined in thin sections, the junctions are perfectly sharp, nor is there the slightest sign of any absorption of the andesites having taken place.

It is, therefore, supposed that the Borrowdale rocks were cold

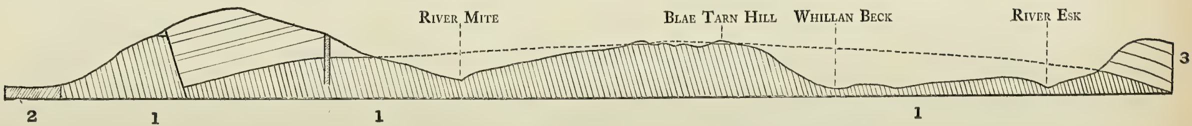
N.N.W. S.S.E.

Fig. 1.—*Section from Wastwater to the Woolpack in Eskdale.* (*Scales, horizontal & vertical : 2 inches=1 mile.*)



W. E.

Fig. 2.—*Section from Easthwaite to Boot in Eskdale.* (*Scales, horizontal & vertical : 2 inches=1 mile.*)



[1=Eskdale Granite. 2=Ennerdale Granophyre. 3=Borrowdale Beds.]

at the time of intrusion of the granite, and that the margin of the latter was rapidly chilled, further intrusion having lifted the overlying masses and produced the dome-like structure indicated by the dips of the Borrowdale Series and of the granite-surface.

There is some slight indication of successive intrusion on the flanks of Hollinghead Bank, near Beckfoot Station on the Ravenglass & Eskdale Railway. At the points marked 160, 162, 163, 164, & 168 on my MS. maps the granite is coarse-grained and reddish in colour, while lower down the slope (that is, farther from the upper surface of the intrusion) at 88, 89, & 90, where a small quarry has been opened, it is fine-grained and grey in colour. The same fine-grained variety occurs at the quarry near Spout House (91 & 92); while above, on Hollinghead Crag, at 172 & 173, coarse granite of the normal type is to be found. The boundary of this low-level fine-grained variety is difficult to trace, owing to the profusion of fallen blocks which encumbers the slope; but, so far as I was able to determine its position, it appeared to run roughly parallel to the upper surface of the intrusion.

The small exposure of granite at Wasdale Head is of the same general type as that found in the Mitredale and Eskdale sections, and exhibits many of the same marginal phenomena, although these are not so well marked as in the case of the larger mass. In several places veins of granite may be seen penetrating the Borrowdale rocks, as, for example, in Gable Beck and near the Waterfall in Mosedale Beck.

Petrology of the Normal Granite.

There are, apart from the marginal varieties, two main types to be seen in the Eskdale Granite—one occupying the north-eastern and by far the larger portion of the main outcrop together with the smaller mass at Wasdale Head, being coarse-grained and containing a considerable quantity of muscovite and a smaller amount of biotite, usually much decomposed; and the other and far less widely distributed variety occurring in the neighbourhood of Wabberthwaite in the south-west, where it is now extensively quarried. It contains a much larger proportion of black biotite, and somewhat resembles in general appearance some of the darker-coloured varieties of the Dumfries-shire granites.

The rocks vary greatly in colour, being in some localities white to grey, while in others they are pink or even red.

Quartz is very plentiful in all the varieties, and is usually free from strain-shadows, although these occur in some parts near the great lines of fault and near the margins of the intrusion. Occasionally small flakes of muscovite occur embedded in the quartz-crystals, which also contain fluid and gas-inclusions, as described by Clifton Ward and others.

The felspars include orthoclase, oligoclase, and a perthitic intergrowth of orthoclase and oligoclase. This perthitic inter-

growth is by far the most common felspathic ingredient of the rock. The orthoclase apparently plays the part of host, the inclusions of plagioclase being irregular in shape but usually having their greatest dimensions in the direction of the orthodiagonal of the orthoclase, and being so arranged that their twin lamellæ (albite-law) are parallel to the clinopinacoid of the orthoclase. In many instances the plagiolase-inclusions are of sufficient size to allow of their extinction being measured; and, as the result of a large number of such measurements, using the twin striation as the index-plane, I have arrived at the conclusion that the felspar is oligoclase, and not albite (as is more usual in such intergrowths).

The presence in such large quantities of this peculiar form of perthite should serve as a valuable means of identifying doubtful cases of erratics from this source.

The micas include both muscovite and biotite, the former predominating, except in the local variety found at Wabberthwaite. The muscovite is usually quite fresh, but the biotite is often represented by chlorite, or near the great ironstone-veins by skeletons of hæmatite together with a little calcite.

The granite is remarkably free from accessory minerals, even apatite being exceedingly rare. In one specimen only I found a small quantity of tourmaline, but in several there was a little magnetite which, being associated with decomposed biotite, I conclude to be secondary.

Order of Separation of the Minerals.

In the normal granite the micas appear to have been the earliest secretion of the magma and to have separated simultaneously, being usually found in parallel intergrowth. The next secretion was apparently in most instances the oligoclase, which was followed by the perthite, orthoclase, and quartz in that order, although, as will be shown later, simultaneous separations and even reversals of some of the terms in the sequence occurred at least locally.

As a general rule, the granite is chiefly made up of quartz and perthite, the micas being present only in small quantity.

Micropegmatitic structure occurs, though rarely, and it is of a coarse-grained type very unlike that of the Ennerdale Granophyre. It usually consists of quartz and orthoclase, but instances are not wanting in which it contains perthite in place of orthoclase (6). In some instances a band of micropegmatite surrounds a crystal of orthoclase, having grown on to it in zonal fashion, so that the quartz-granules in the two portions of a Carlsbad twin are differently oriented as regards their extinction (9). This zonal arrangement of micropegmatite shows that, in this instance, its formation immediately succeeded that of the orthoclase.

Micropegmatite is usually the last secretion of a rock in which it occurs; but, in this case, the orthoclase-crystal, with its zone of micropegmatite, is surrounded by a ground-mass of quartz and felspar in a fine mosaic, although exhibiting no trace of micropegmatitic

structure. In other cases the micropegmatite is very coarse-grained, and not definitely connected with any phenocryst of felspar.

In several instances, as noted by Dr. Teall,[1] quartz is included in felspar, and this applies equally to orthoclase, perthite, and oligoclase.

An instance of quartz embedded in oligoclase is illustrated by a specimen from Mitredale Head (66). (See Pl. III, fig. 2.)

Further evidence of this abnormal order of separation is to be found in some of the fine-grained varieties near the margins of the intrusion, where phenocrysts of quartz, in one instance corroded as in the quartz-porphyries, occur in a quartz-felspar matrix (Pl. III, fig. 3), and in the fact that the extreme margins of the laccolite, the first portions to solidify, consist of almost pure quartz. (See chemical analysis, p. 64.)

Secondary Minerals.

Hæmatite is present as a secondary mineral, and occurs in veins and patches; while in some instances it forms a fringe round the crystals of quartz and felspar, and in others impregnates crystals of muscovite where they are crossed by cracks (3).

Cracks filled with secondary quartz, in a fine mosaic, are occasionally seen to cross crystals of felspar. Chlorite is a common decomposition-product of biotite in the more weathered specimens.

Petrology of some Varieties of the Granite.

The Wabberthwaite variety (182).—This is a medium-grained dark-grey granite, in which biotite is much more plentiful than in other localities.

It consists of quartz, orthoclase (kaolinized), and a smaller quantity of perthite, with considerable quantities of biotite in a fairly fresh condition, and subordinate muscovite. The order of separation of the minerals seems to be normal.

There are also numerous veins of aplite in the Wabberthwaite Quarries.

At Stainton-Mill Dam (183) is a small exposure of a pink granitoid rock, which is unlike anything met with in other parts of the area. Under the microscope it is similar to the Wabberthwaite variety of the granite, except that it contains considerable quantities of a pale-green pleochroic amphibole.

The exposure is small and its boundaries are not seen, hence it is impossible to determine its relation to the normal variety; but, as it occurs in the midst of the granite-mass and possesses many characters in common with it, it does not seem probable that it is a separate intrusion. It may possibly be due to the inclusion and absorption of a mass of the country-rock (Borrowdale andesite) as described by Dr. R. A. Daly (Am. Journ. Sci. ser. 4, vol. xxvi, 1908, p. 19); but, if so, it is the only evidence of this action that I have seen in the district.

[1] 'British Petrography' 1888, p. 323.

The marginal varieties.—Reference has already been made to the changes in texture and composition which the granite undergoes as the margin of the intrusion is approached, and it is now proposed to describe some of the marginal varieties in greater detail.

The rock, as one would expect from the more rapid cooling which must have prevailed along the margins of the intrusion, is much finer in texture than in the more central parts. Another change, one of composition, accompanies this, a change which at first sight is not so easy of explanation. Samples of the normal Eskdale Granite were found on analysis to yield from 71·86 to 76·43 per cent. of silica, but specimens nearer the edges showed a progressive increase in the silica-percentage, until at the extreme edge of the granite in Hardrigg Gill (80) the rock contained 96·16 per cent. of silica.

In every case in which I was able to examine the actual junction of the granite with the Borrowdale rocks, these extremely acid varieties were present, though the percentage of silica was usually not so high as in the case of the Hardrigg-Gill specimen, being more commonly in the neighbourhood of 90 per cent.

Analyses of the Normal Granite and of the Marginal Specimen No. 80.

	Specimen 79. Normal granite.	*Specimen 80. Marginal variety.*
	per cent.	per cent.
SiO_2	76·43	96·16
Al_2O_3	13·56	1·31
Fe_2O_3	0·08	0·02
FeO	0·55	0·09
MgO	0·54	0·03
CaO	0·03	trace
Na_2O	4·19	0·56
K_2O	4·72	0·30
H_2O (combined)	0·76	0·51
H_2O (free)	0·06	0·08
Totals	100·92	99·06

Marginal varieties from Robin Gill (Mitredale).—An exposure in the stream known as Robin Gill shows a fine-grained granite of a pinkish colour (51); while at (53) close to the Upper Waterfall the rock is of a felsitic texture, with small porphyritic crystals of quartz and felspar, and a few dark red patches apparently stained by hæmatite. At (54), nearer the junction, it is generally similar, but with the porphyritic constituents less conspicuous.

Specimen 53.—A fine-grained, pink, felsitic rock, with small porphyritic crystals of quartz and felspar. The ground-mass is a fine-grained mosaic of quartz and felspar, with phenocrysts of quartz, orthoclase, perthite, and oligoclase, also of biotite which has passed over into chlorite and hæmatite. The rock moreover

shows a somewhat unusual type of micropegmatitic structure. This consists of a growth of quartz about a much-decomposed crystal of oligoclase; the quartz, although very irregular in form, is apparently a single crystal, as all parts of it extinguish simultaneously; it is penetrated by smaller individuals of a felspar, which I was unable to identify, in true micropegmatitic fashion.

Specimen 54 is a similar rock to No. 53, but rather deeper in colour and with the porphyritic elements less conspicuous. It contains a few minute flakes of muscovite which, however, appear to be secondary.

Marginal varieties from Hardrigg Gill.—The various marginal types are well exposed in Hardrigg Gill, and specimens 78, 79, 80, 80 A, 80 B, & 81 were collected in the stream, 78 being farthest from the edge of the intrusion, while 81 was an actual junction-specimen. These specimens are described somewhat fully, as they constitute the best series of the marginal varieties which have been collected.

Specimen 78.—A medium-grained granite consisting of quartz, pink felspar, and a greyish mica.

The minerals are quartz, perthite, oligoclase, biotite, and muscovite, with apatite as an accessory. The biotite and muscovite are in parallel intergrowth, and the former has passed over into a green decomposition-product, apparently chlorite. The muscovite is present in large amount, as compared with the biotite. There are some minute particles, of a brownish-yellow mineral resembling augite, in one part of the section.

Specimen 79 (see chemical analysis, p. 64).—Less even in texture and somewhat finer-grained than 78, grey in colour, and showing larger grains of quartz and nests of mica.

The minerals are green biotite with muscovite in parallel intergrowth, perthite, oligoclase, and quartz. Threads of muscovite appear to run off from some of the larger crystals into the crystals of perthite. Micropegmatitic structure occurs, but only to a small extent.

Specimen 80 (see chemical analysis, p. 64; also Pl. III, fig. 4).—A rock of fine-grained granitic texture, but consisting almost entirely of quartz, with a few greenish veins traversing it. It is a fine-grained mosaic of quartz, with a few minute flakes of muscovite. The grains of the mosaic average 0·25 millimetre in diameter. Felspars and biotite are absent. The specific gravity of the rock is 2·62.

Specimen 80 A.—Slightly darker in colour and coarser in texture than No. 80, but consisting of quartz with minute wisps of muscovite, and a small quantity of ilmenite apparently associated with the muscovite.

Specimen 80 B.—Similar in texture to No. 80 A, but pink in colour. It is an aggregate of quartz and perthite, with a less

quantity of oligoclase and orthoclase. Biotite is represented sparingly by decomposition-products. Muscovite is also present in small quantity.

Nos. 80, 80 A, & 80 B were all collected within a length of 20 yards, along a line at right angles to the outcrop.

Specimen 81.—This specimen shows the actual junction of the granite with a highly altered andesitic lava. The acid rock has the appearance and texture of a quartz-porphyry, while the Borrowdale lava is dark grey in colour and consists largely of secondary mica.

The granite is similar in type to No. 80, but somewhat finer in texture and containing a considerable amount of felspar. It also contains phenocrysts of quartz and small nests of decomposed biotite, with a few phenocrysts of oligoclase. The quartz-phenocrysts show strain-shadows, and the rock resembles a quartz-porphyry with a microgranitic base.

The Borrowdale rock consists of a very fine mosaic of quartz, with abundant minute crystals of secondary brown mica. There are also traces of larger crystals of biotite, which were proper to the rock before the intrusion of the granite. The junction between the two rocks is very sharply defined, and there is no sign of absorption having taken place. (See Pl. III, fig. 6.)

Whinscales.—The marginal zone occurs near the sheepfold at a height of 1200 feet, and is unusually thin; but there is a well-marked breccia, consisting of angular fragments of Borrowdale rocks in a granitoid matrix.

Specimen 100 A.—This is a somewhat unusual type, but I have collected it in several other parts of the area, where it always occurs just within the belt of fine-grained acid material that constitutes the extreme edge of the intrusion. It contains large and extremely thin films of biotite which coat the faces of the larger felspar-crystals, and, when seen in transverse section, look like acicular crystals. They are dark grey in colour, the remainder of the rock being pink.

Under the microscope the rock shows quartz, perthite, orthoclase, albite, and broad (but extremely thin) crystals of biotite which often exhibit the transition into chlorite. Muscovite appears to be absent. There are slight indications of micropegmatitic structure.

This rock passes gradually into the usual marginal variety, consisting of a very fine-grained aggregate of quartz, with a little orthoclase and, in this instance, a few minute flakes of biotite. The actual contact is exposed, and is seen to be perfectly sharp.

Specimen 101.—This is a specimen of the junction collected a few yards away from the sheepfold. The intrusive portion is a pink felsitic rock, consisting of a fine quartz-orthoclase mosaic with a few minute flakes of biotite. The contact is quite sharp, a large phenocryst of felspar in the Borrowdale rock being cleanly cut across.

Stony-Tarn area.—In this area (129), near the margin of the granite, occurs a granitoid rock which is distinctly porphyritic in appearance. The phenocrysts are of quartz and muscovite, and the ground-mass is a microcrystalline aggregate of quartz, felspar, muscovite, and biotite. The rock is, in fact, a quartz-porphyry.

Between Goat Crag and Whin Crag (130, 131, & 132) is a good exposure of the junction-breccia, of which fig. 3 is a photograph;

Fig. 3.—*Junction-breccia near Stony Tarn.*

[The white veins are of marginal granite, and penetrate a dark andesitic lava.]

while fig. 4 (p. 68) represents a hand-specimen of the same rock collected at 131, Pl. III, fig. 5 illustrating a thin section of the same.

The Borrowdale rock was apparently a porphyritic andesite before alteration. The ground-mass now consists of minute flakes of brown, slightly pleochroic biotite, with a little muscovite, felspar, and quartz. The phenocrysts of pyroxene have been converted into a meshwork of pale amphibole, with a little secondary quartz. A pale pyroxene also occurs in smaller quantities. A few phenocrysts of felspar have been altered, and now contain flakes of muscovite.

The granitoid rock is a fine-grained mosaic of quartz, containing in the broader veins phenocrysts of quartz, orthoclase, and oligoclase.

Ferromagnesian minerals are represented by a very small quantity of greenish biotite, quite unlike the variety which occurs in the altered andesite.

The junction is everywhere sharp, and there is no sign of absorption of the andesite having taken place. One of the felspar-phenocrysts in this specimen is cut clean across by the contact-line.

Fig. 4.—*Hand-specimen of junction-breccia, from near Stony Tarn. (See also p. 67.)*

An examination of fig. 4 will show that the andesite-fragments in the breccia are extremely angular, in some instances possessing knife-like edges.

Many larger granite-veins penetrate the Borrowdale rocks in the same area, and consist of a pink, fine-grained, very acid granite, in which quartz and felspars are the principal constituents. Specimen 132, from one of these larger veins, shows the usual quartz-mosaic with larger crystals of perthite, quartz, oligoclase, and also phenocrysts of micropegmatite. There are narrow secondary veins of a mixture of epidote and quartz, running in various directions across many of these granite-veins.

Specimen 108 was taken from the quartz-vein which occurs at the junction of the granite with the Borrowdale rocks, one-third of a mile north of Taw House in Upper Eskdale, and already

referred to on p. 57. It consists of allotriomorphic quartz in masses at least ten times the size of those ordinarily found in the marginal mosaics. Strain-shadows are to be seen in nearly every crystal. Felspar and mica are entirely absent, and the crystals of quartz are fimbriated along their margins and closely interlocking. Furthermore, they contain numerous minute specks of a mineral possessing a high refractive index and strong double refraction, but which I have been unable to identify. In the hand-specimen this vein is precisely similar to those so commonly found in the Skiddaw Slates, and I do not consider it to be of igneous origin. It is quite different, both in appearance and in structure, from the marginal varieties of the granite.

Some Theoretical Considerations.

The fact that the granite-mass becomes more acid toward its margin is of considerable interest from a theoretical point of view.

The normal granite is more acid than the average, containing as it does about 75 per cent. of silica; and this I consider to be the explanation of the unusual marginal phenomena. It is a well-known fact that in the case of substances which form eutectic mixtures, where either of the constituents is present in excess of the quantity necessary to form the eutectic, that constituent separates out first, until the molten residue reaches eutectic proportions.

It may be considered as demonstrated that quartz and orthoclase are capable of forming an eutectic mixture, and that this eutectic plays an important part in the formation of igneous rocks, appearing as graphic and micropegmatitic structures.

That this is not the only eutectic that occurs in magmas seems to be indicated by the occurrence of similar micropegmatitic intergrowths of other minerals; and I am inclined to regard certain other intergrowths, which do not exhibit the same type of structure in their solid form, as being due to the existence of an eutectic mixture of their constituents in the magma at a certain stage of its consolidation. Thus, the parallel intergrowths of biotite with muscovite may be due to this cause; and there seems even greater reason for supposing the 'perthite', so common in the granite under consideration, to be a solidified eutectic.

The difference in the texture and structure of these various intergrowths may be explained on the hypothesis that the structure is controlled by the crystalline form of the constituents. Thus, in the parallel intergrowth above mentioned both minerals belong to the same system. In the case of perthite, where there is also a certain parallelism, the systems of the two constituents are not greatly dissimilar, being monoclinic and triclinic respectively; while in the quartz-orthoclase micropegmatite, where anything in the nature of parallelism is exceptional, the crystalline systems of the constituents are widely removed from each other as regards symmetry, being monoclinic and hexagonal.

However this may be, the fact that these intimate intergrowths occur points to a simultaneous separation of their constituents, a phenomenon which demands an explanation.

The presence in a rock of more than one pair of minerals which owe their origin and association to the solidification of an eutectic mixture, will probably be found to be due to the successive existence of a number of such mixtures in the magma at different stages of its cooling. It may well be that, as the magma cools, an eutectic association takes place, that this gives rise to the simultaneous solidification of a pair of minerals, and that at lower temperatures certain phases may detach themselves and form other eutectic associations, stable at these lower temperatures, thus breaking up the earlier one, and in their turn giving rise to other intergrowths.

It is now well known that changes in the molecular constitution of steel and alloys take place during cooling after solidification, one of these being the breaking-up of a solidified eutectic into a coarser-grained mosaic of its constituent compounds, with the obliteration of the characteristic eutectic structures. This change can be demonstrated both by cooling-curves and by microscopic examination, and the non-occurrence of micropegmatitic structure in many of the quartz-felspar ground-masses may be due to some such change. The experimental investigation of these matters is not easy. The high melting-points of the substances are in themselves a difficulty, and the extremely slow rate of cooling necessary to ensure the crystallization of the silicates renders the study of cooling-curves and volume-changes extremely difficult, if not well-nigh impossible.

To return to the question of the acid margins of the granite. It is, of course, well known that most batholiths, especially those of basic composition, vary considerably in composition as between their central and peripheral parts, the edges of the intrusion being usually more basic than the interior.

In the case of the Eskdale Granite, it is my opinion that the reversal of the usual distribution, namely, the occurrence of the more acid rock on the periphery and the more basic in the interior, is due to the magma as a whole having been more acid than some eutectic, probably that of quartz and orthoclase, and the consequent primary separation of quartz until the eutectic proportions were reached, at all events locally.

The case for the early separation of quartz from the magma does not rest on the marginal phenomena alone: for, as has already been stated (p. 63), the rock contains examples of quartz-crystals enclosed in phenocrysts of oligoclase and other felspars; while the presence of phenocrysts, similar to those that occur in the quartz-porphyries, in some of the finer-grained varieties, points in the same direction. One cannot, however, expect a complete solution of this problem without further experimental work.

III. The small Intrusions near Peers Gill. (Fig. 5, p. 72.)

Peers Gill is a steep-sided gorge excavated in the Borrowdale Series, partly along a line of fault and partly along an ironstone-vein. It lies in the angle between Lingmell and Great End, and drains the northern slope of Scafell Pikes.

In the neighbourhood of the gorge numerous exposures of intrusive rocks are seen, varying somewhat in texture, but resembling each other in chemical composition, and connected by a number of dykes. Somewhat similar rocks also occur on Lingmell Crag, and at Bursting Knotts on the opposite side of Upper Wasdale.

Specimen 232.—The rock from Bursting Knotts, a small exposure immediately south of the path leading from Wasdale Head to Sty-Head Pass, is dark grey in colour and holocrystalline in texture, the felspars showing signs of a change to epidote. In section, the texture is seen to be granitic, and the rock contains quartz, orthoclase, andesine, a large quantity of brown biotite (now somewhat chloritized), and a considerable quantity of epidote.

Of the rocks from the foot of Peers Gill, that from 233 A is a pink felsitic rock, with a microcrystalline ground-mass consisting for the most part of felspar, but with some quartz. It contains many phenocrysts of andesine and an occasional phenocryst of orthoclase, there being also some epidote and a little hæmatite.

Specimen 233 B is a somewhat similar rock, but more basic in composition. It contains numerous pseudomorphs in chlorite and epidote, apparently after a pyroxene.

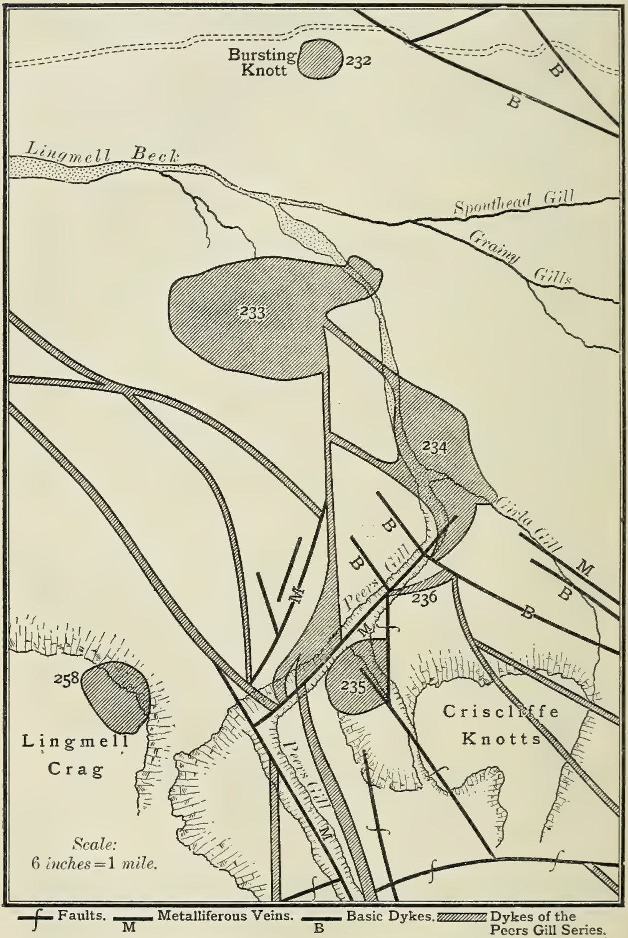
Specimen 233 C.—This seems to be a highly-altered diorite, and consists very largely of chlorite and secondary biotite, with considerable quantities of felspar playing the part of ground-mass.

Specimen 234.—From the junction of Peers Gill and Girta Gill comes a greyish hemicrystalline rock with a mottled appearance. The ground-mass is very fine-grained, and consists of small clear felspars and quartz. There are numerous phenocrysts of an oligoclase-andesine, which frequently show zonal structure. Deep brown and strongly pleochroic biotite is also abundant. The biotite is fresh, except on the edges of the crystals, where a change to chlorite has set in. There are also numerous pseudomorphs apparently following pyroxene, and consisting of a mixture of calcite, magnetite, and biotite. The rock is an altered andesite.

The rock from Lingmell Crag is similar, both in texture and in composition, to Specimen 232.

These rocks show a community of character among themselves, but are petrologically quite unlike anything in the areas occupied by the Eskdale Granite, either in the main exposure or in that at Wasdale Head. It is assumed in the Horizontal Section (Sheet 114) of the Geological Survey, that one of these, namely that on Lingmell

Fig. 5.—*Map showing the dykes and other intrusions near Peers Gill.*



[*For* 'Bursting Knott,' *read* 'Bursting Knotts.']

Crag, is an offshoot of the Eskdale Granite; but, as it will be shown that dykes belonging to this series are cut and displaced by those connected with the granite, and as the rocks themselves are chemically and mineralogically unlike the Eskdale Granite, it seems more probable that all these smaller intrusions are independent of, and older than, that rock.

IV. The Dykes.

An inspection of the 1-inch maps of the Geological Survey reveals a very large number of dykes intersecting the Borrowdale rocks of the district.

These dykes are divided into three groups, namely, felsite, quartz-felsite, and basalt; and it is apparently assumed by the Geological Survey (judging from the published sections) that the felsite and quartz-felsite dykes are connected with the granite-intrusion, the basic dykes being much later, cutting and in some instances displacing the acid intrusions.

The quartz-felsites appear to be represented by a single large dyke running from Great Bank near Eskdale Green (at which locality it occurs as a vein in the granite itself) by way of the south-eastern slope of the Screes, where it enters the Borrowdale Series, to Wasdale Hall at the head of Wastwater. Thence it passes across Lingmell Gill and the north-western flank of Lingmell to the granite-exposure at Wasdale Head, which it appears to penetrate. On the opposite side of the granite, it can be traced from the neighbourhood of Burnthwaite up the side of Eskdale Fell, and across the summit of Kirk Fell to Bayscar Slack, at the foot of Kirkfell Crags. This appears to be the only dyke that is undoubtedly connected with the granite-mass, with which it agrees petrologically.

The 'felsite'-dykes occur mainly in three areas:—

(1) On Yewbarrow and High Fell.

(2) Near Allen Crags and Angle Tarn.

(3) Along a line from Kirkfell Crags on the north-west, by way of Peers Gill and Little Narrow Cove, on Scafell Pikes, to Bowfell on the south-east.

The Quartz-Felsite Dyke.

This dyke, which is, in my opinion, the only one that is connected with the Eskdale Granite, consists of a reddish holocrystalline rock of the quartz-porphyry group. It exhibits large and well-marked porphyritic crystals of felspar and quartz, with a smaller quantity of mica, in a microgranitic ground-mass. Some of the larger orthoclase-phenocrysts exhibit distinct zonal structure and a tendency to change into epidote.

The Dykes on Yewbarrow and High Fell.

Specimen 201, collected from a dyke on the left bank of Over Beck, between Overbeck Bridge and Bowerdale Farm, consists of a dark-grey fine-grained rock, much jointed, and presenting the appearance of a rhyolite. The ground-mass is felsitic, with marked flow-structure, and is considerably stained by hæmatite. There are phenocrysts of felspar, but they are so much decomposed as to render it impossible to identify them with certainty: their habit, however, suggests that of andesine. The rock also contains pseudomorphs after pyroxene or amphibole, or after both.

A little higher up the stream the dyke is shifted about a sixth of a mile to the north-east by a fault, and then follows the course of Over Beck to the junction of Brimfull Beck with that stream. Specimens collected at 203, 204, 205, 206, & 207 along the course of the dyke, were found to be similar in constitution to that just described.

Specimen 208, from a dyke crossing Brimfull Beck, is of similar character.

Specimen 209, from another dyke a little higher up the same stream, is a pink felsite which is non-porphyritic. It consists of a fine mosaic of felspar and quartz, with small wisps of chlorite, probably after biotite.

Specimen 210, from the dyke which forms the waterfall in Nether Beck, about 100 yards above Netherbeck Bridge, is very similar to 209.

Specimens 211 to 214, from the dykes so numbered on my MS. map, consist of a highly-decomposed pink felsite with marked spherulitic structure, and containing much secondary epidote and chlorite.

Specimens 215 to 224 form a network of dykes on the high ground between Nether Beck and Over Beck. They possess the same general characters as Nos. 211 to 214 just described, but vary somewhat as regards the coarseness of their texture.

Specimens 228 to 231 are of pink felsite, with spherulitic structure similar to that exhibited by Nos. 215 to 224.

The above form a group of dykes closely related to each other, and possessing marked similarity of composition.

The Dykes near Allen Crags and Angle Tarn.

In this group are included Nos. 237 to 242, which are all andesitic in composition, and bear a general similarity both to one another and to the andesitic lavas of the Borrowdale Series, with which they are associated. Specimen 237 will serve as an example.

Specimen 237, collected close to the edge of a small tarn

north of Allen Crag (B.M. 2185.4), is a grey andesite. The ground-mass is principally felspar and chlorite, and the phenocrysts are chiefly of andesine. There are also large pseudomorphs in calcite and chlorite after pyroxene, and smaller ones after biotite.

The Dykes of Group 3. (Figs. 5 & 6, pp. 72 & 76.) (Nos. 236 & 249 to 256.)

There are numerous dykes connected with the intrusions at Bursting Knotts and Peers Gill, and extending north-westwards on the one hand to Kirkfell Crags, and south-eastwards on the other to the neighbourhood of Angle Tarn, by way of Little Narrow Cove. Descriptions of several varieties of rocks from this series follow.

Specimen 236.—A pink felsitic rock, much streaked with dark-green matter. The ground-mass is cryptocrystalline, and there are many porphyritic crystals of andesine, also pseudomorphs in epidote after an amphibole or a pyroxene. Numerous veins of epidote and chlorite traverse the rock, imparting to it the streaked appearance noted in the hand-specimen. Evidently, the rock is an altered andesite. The dykes in Little Narrow Cove show some slight variation in character, but, on the whole, are of andesitic type.

Specimen 250 A is a fine-grained rock of granitic texture, and consists of quartz, white felspar, and streaks of dark-green matter. Microscopic examination reveals orthoclase and plagioclase, with large quantities of chlorite after biotite and of epidote.

Specimen 250 B is greenish in colour, and shows marked porphyritic structure, felspar and dark-green pseudomorphs being conspicuous. The ground-mass is felsitic, and there are large phenocrysts of andesine, with a smaller quantity of orthoclase and a few crystals of quartz which are corroded. Chlorite and epidote, apparently after biotite, are also present in considerable quantity. The rock moreover contains numerous small needles of apatite.

Specimens 251 to 256 are similar as regards their general characters to No. 250 B, although they are somewhat finer in texture.

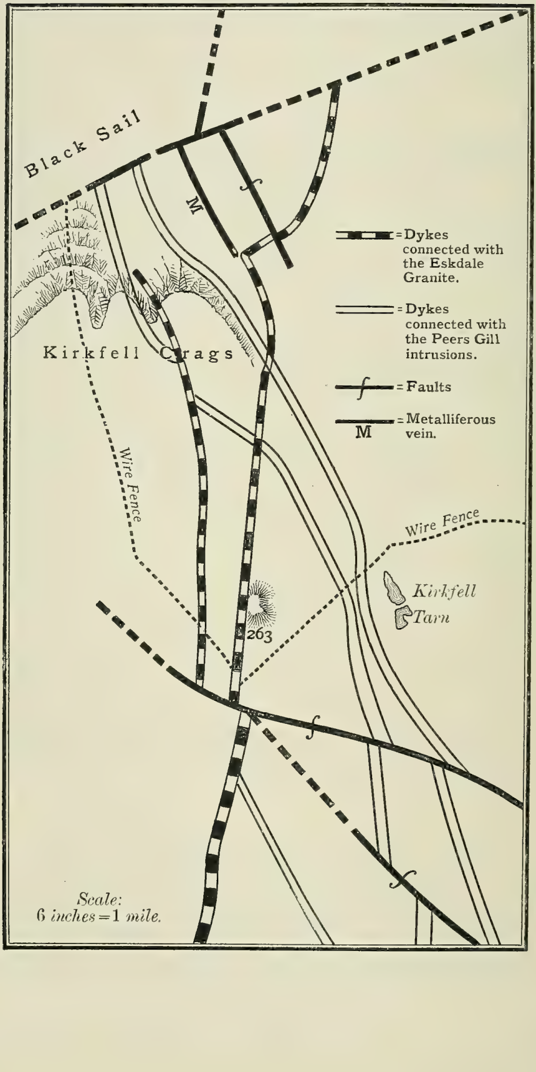
Specimen 249, at the foot of Skilling Crag, is distinctly andesitic in character. It contains much epidote, with oligoclase and andesine. There is no quartz, and the ground-mass is cryptocrystalline.

V. General Relations of the Intrusive Rocks.

The dykes on Kirkfell Crags consist of two sets (fig. 6, p. 76)—one with a north-west to south-east trend, and the other running in a north-east to south-west direction.

Of these, the former consists of a group of two main dykes, which, though cut and displaced by several faults, can be traced by Kirk Fell and Ill Gill to Gable Beck, where they form the two

Fig. 6.—*Map showing the dykes on Kirk Fell.*



waterfalls, and thence to Flass Knotts and Peers Gill, and one or two minor offshoots of these. These dykes are certainly connected with the intrusions of 'bastard granite' at Peers Gill, and form a continuation of the two main dykes in Little Narrow Cove.

The other set consists of the great dyke of granite-porphyry already mentioned (p. 73) as connected with the Eskdale Granite, and a smaller offshoot of the same.

Reference to fig. 6 (p. 76) will show that the dykes connected with the Peers-Gill intrusions are cut, and in one instance displaced, by the dyke of granite-porphyry, indicating that this is the younger intrusion.

Thus, there appear to be five well-marked groups of intrusions in this district:—

(*a*) The andesitic dykes in the neighbourhood of Allen Crags and Angle Tarn.

(*b*) The dykes of the spherulitic and felsitic group on Yewbarrow and High Fell.

(*c*) The dioritic ('bastard granite') bosses of Peers Gill, Lingmell Crag and Bursting Knotts, with their associated dykes.

(*d*) The Eskdale Granite, with the granite-porphyry dyke running from Great Bank to Wasdale Head and thence to Kirkfell Crags.

(*e*) The dolerite-dykes, having a general north-west to south-east trend.

The dykes of series (*a*) bear a very strong petrological resemblance to the Borrowdale volcanic rocks into which they were intruded. Furthermore, they are weathered to much the same extent, and have developed the same secondary minerals, among which epidote is conspicuous. They appear to me to be of Borrowdale age, and roughly contemporaneous with the lavas and ashes among which they are intruded.

The spherulitic series (*b*) is more acid in type; but here again the amount of alteration is very great, and the rocks are similar to many of the rhyolitic lavas found in the upper part of the Borrowdale Series. These also are considered to be of Borrowdale age, although probably somewhat later than the andesitic series (*a*).

The rocks of the dioritic group (*c*), though less altered than those of groups (*a*) & (*b*), are still far from fresh; and, furthermore, the changes which have taken place in them are similar to those that have affected the Borrowdale lavas, a notable feature being the great development of secondary epidote. These may well be the holocrystalline and hypabyssal equivalents of the Borrowdale lavas, and I am of opinion that they also are of Ordovician age.

My chief reason for thinking that these rocks have had a separate origin from the Eskdale Granite is the marked contrast in composition which they show to that rock. As I have already pointed out, the principal felspars in the granite are orthoclase and perthite (orthoclase-oligoclase); but, in the smaller intrusions of Peers Gill, orthoclase is uncommon and perthite wholly absent, while oligoclase-andesine and andesine, unknown in the granite, are present in

considerable quantity. Further, in the minor intrusions biotite is present in large quantity, while in the granite muscovite is the dominant mica. There are also pseudomorphs after either a pyroxene or an amphibole, both of which minerals are absent from the normal granite of both Eskdale and Wasdale Head.

(*d*) The Eskdale and Wasdale Granites and their associated dyke are much more acid than any of the other rocks hitherto mentioned, and they show comparatively little alteration, with the exception of that due to weathering along the great lines of dislocation occupied by the ironstone-veins. They are undoubtedly intrusive in the Borrowdale Series, and the western boundary of the main intrusion, as shown on the maps of the Geological Survey and as confirmed in the field, very strongly suggests that they are pre-Triassic. Unfortunately, no clear exposure of the junction with the Trias could be found; but the similarity of the relation which the Triassic outcrop bears to the granite and to the Borrowdale rocks is strong evidence of the existence of the granite before the Triassic Period. It seems probable that this intrusion belongs to the Devonian Period, as does the neighbouring granite of Shap, which, with the exception of its large phenocrysts of orthoclase, is not dissimilar to some of the varieties of the Eskdale Granite (as, for example, the Wabberthwaite variety).

(*e*) The basic intrusions have not yet been examined, except in one or two instances where they come into proximity to the granite. They are, however, undoubtedly the latest intrusions in the area, and may be seen cutting and displacing any of the others with which they come into contact. Although basic in composition and containing olivine, they are much less altered than any of the other intrusive rocks. They may well be connected with the great Tertiary basic flows of Antrim, as has, I believe, been suggested by Mr. Harker.

My thanks are due to Mr. R. H. Rastall for information respecting the neighbouring intrusion of granophyre; to Mr. Cosmo Johns for many facts recently added to our knowledge of the structure of alloys; and to Messrs. C. G. Jackson & G. V. Wilson for analyses of rock-specimens.

EXPLANATION OF PLATE III.

Fig. 1. Crystal of perthite (orthoclase-oligoclase) in Eskdale Granite. Slide 78, magnified 23 diameters. See pp. 61–62.

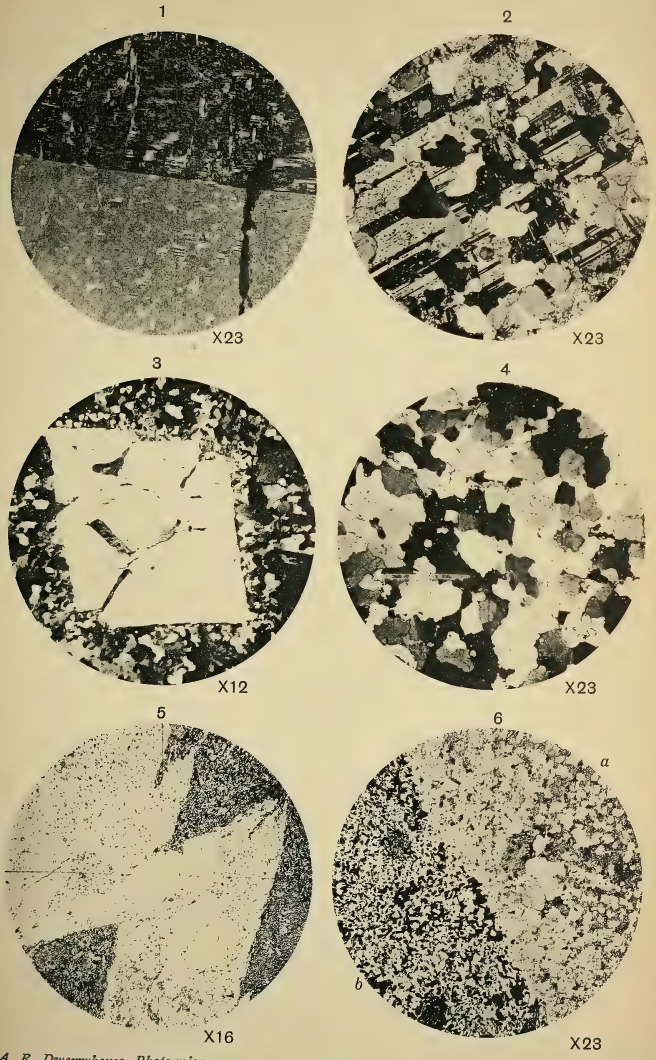
2. Quartz embedded in oligoclase, Eskdale Granite. Slide 66, magnified 23 diameters. See p. 63.

3. Phenocryst of quartz in the marginal variety of the Eskdale Granite. Slide 7, magnified 12 diameters. See p. 63.

4. Quartz-mosaic from the margin of the Eskdale Granite. Slide 80, magnified 23 diameters. See pp. 63 & 65.

5. Junction-breccia from near Stony Tarn. Slide 131, magnified 16 diameters. See pp. 67–68.

6. Junction of granite (*a*) and altered Borrowdale lava (*b*), near Stony Tarn. Slide 81, magnified 23 diameters. See p. 66.



A. R. Dwerryhouse, Photo-micro.

Bemrose, Collo., Derby.

IGNEOUS ROCKS FROM ESKDALE.

Discussion.

Dr. Teall said that the paper was evidently an important one, but that, in view of the demonstration which was to follow, he would only make one remark: the fact that the Eskdale Granite had a very acid margin appeared to furnish another illustration of the general law, that those substances which crystallize first from the average magma—an acid one in this case—tend to concentrate in the cooler parts.

Mr. Barrow, referring to the use of the word 'eutectic' by the Author, suggested that the highly quartzose material, on the outer margin of the intrusion, was really an eutectic compound of low consolidation-point, formed of quartz and water, the latter probably in the form of vapour or steam.

Mr. J. F. N. Green said that the Author's work in disentangling the relative ages of these intrusions would be of the greatest value to others working in the Lake District. So far as the southern edge of the Eskdale mass was concerned, he could confirm the Author's observations; but he considered that, as the relations of the faults on the map shown seemed to indicate, the Eskdale Granite was older than the main crust-movements, whereas the Shap Granite was younger.

Dr. J. W. Evans called attention to the similarity between the inclusions of quartz in the felspars, and those occurring in the rocks allied to granulites described by him from the Rio Madeira, and by Prof. Weinschenk from Ceylon.

Mr. Cosmo Johns commented on the value of the Author's observations, and said that the very acidic margin might be explained by assuming that the excess substance had separated from some eutectic; yet, there was the possible alternative that two liquid phases, one much more acid than the other, existed in the magma and had partly separated, owing to their difference in specific gravity, before intrusion took place. He thought the Author's explanation of the presence of structurally free quartz and felspar, where micropegmatite would be expected, most important. It had been demonstrated experimentally in the case of certain alloys, that if the cooling of the mass be arrested at the point where the eutectic separates out, for a sufficiently long period, the two constituents would segregate and be structurally free. That particular structure, once thought to be characteristic of the eutectic mixture, was therefore but the accident of a particular rate of cooling, and this rate might differ for each eutectic. The usual absence of the structure from rocks where it might be expected to occur could be explained: it was its occasional presence that created the difficulty. The Author's conclusion that the temperature of the mass when intruded was comparatively low seemed well founded. It did not appear that any satisfactory determination of the fusion-point of quartz had been made. The high temperatures given for the fusion-point of silica referred to tridymite. The temperature at which the transformation of quartz into tridymite occurred was

much lower, and he thought that the fusion-point of quartz would be low. He considered that the neglect of experimenters to recognize the quartz-tridymite transformation-point might explain their difficulty in determing the true fusion-point of micropegmatite.

The Author thanked Dr. Teall for his complimentary remarks upon the paper, and Mr. Barrow for his suggestion that an eutectic of quartz and water might have played an important part in the history of the rock; and said that, if this were the case, the difficulty raised by another speaker with regard to the high temperature of the magma at the time of intrusion might be removed. He also expressed his full accord with the views of Mr. Cosmo Johns on the subject of eutectics, and acknowledged many valuable suggestions which he had from time to time received from him. With regard to the question of two liquid phases, the Author pointed out that evidence of the existence of such phases was difficult to obtain; but that, if they could be shown to have existed, many difficulties might be removed.

He welcomed Mr. Green's remarks as to the age of the intrusion, and pointed out that the only direct evidence on this subject was that the granite was intrusive in Ordovician rocks and apparently covered unconformably by the Trias. The dyke of quartz-porphyry on the Screes was indeed displaced by faults, but these probably did not belong to the great pre-Devonian movement, as their lines were frequently occupied by doleritic dykes which were the latest intrusions in the area and were probably of Tertiary age.

In conclusion, the Author thanked the Fellows for their cordial reception of his paper.

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OF

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The Library is open daily to the Fellows between the hours of 10 and 5 (except during the fortnight commencing on the first Monday in September; see also next page), and on Meeting-Days until 8 P.M. Under certain restrictions, Fellows are allowed to borrow books from the Library.

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CONTENTS.

PAPERS READ.

[No. 258 of the Quarterly Journal will be published next May.]

[The Editor of the Quarterly Journal is directed to make it known to the Public that the Authors alone are responsible for the facts and opinions contained in their respective Papers.]

*** The Council request that all communications intended for publication by the Society shall be clearly and legibly written on one side of the paper only, with proper references, and in all respects in fit condition for being at once placed in the Printer's hands. Unless this is done, it will be in the discretion of the Officers to return the communication to the Author for revision.

The Library and Museum at the Apartments of the Society are open every Weekday from Ten o'clock until Five, except during the fortnight commencing on the first Monday in September, when the Library is closed for the purpose of cleaning; the Library is also closed on Saturdays at One P.M. during the months of August and September. It is open until Eight P.M. on the Days of Meeting for the loan of books, and from Eight P.M. until the close of each Meeting for conversational purposes only.

Vol. LXV. PART 2. MAY 29TH, 1909. **No. 258.**

C. A. White

THE

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OF THE

GEOLOGICAL SOCIETY.

EDITED BY

THE ASSISTANT-SECRETARY.

[With Eight Plates, illustrating Papers by Mr. C. I. Gardiner & Prof. S. H. Reynolds, Mr. J. H. Collins, Miss G. L. Elles, Miss M. C. Stopes, and Mrs. Longstaff.]

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EVENING MEETING OF THE GEOLOGICAL SOCIETY TO BE HELD AT BURLINGTON HOUSE.

Session 1908–1909.

1909.

Wednesday, June 16*

[*Business will commence at Eight o'Clock precisely.*]

The date is marked with an asterisk, to show that the Council will meet that day.

ANNUAL GENERAL MEETING,

February 19th, 1909.

Prof. W. J. Sollas, LL.D., Sc.D., F.R.S., President, in the Chair.

Report of the Council for 1908.

Although the past year was again marked by an increase in the Number of Fellows, this increase was small in comparison with that recorded in the two previous years. In 1908 the Fellows elected numbered 52 (as compared with 74 in 1907), and 37 of these paid their Admission-Fees before the end of the year. Moreover, 15 Fellows who had been elected in the previous year paid their Admission-Fees in 1908, making the total Accession of new Fellows within the twelve months under review amount to 52.

Setting against this number a loss of 47 Fellows (22 by death, 21 by resignation, and 4 by removal from the List, under Bye-Laws, Sect. VI, Art. 5), it will be noted that there is an increase in the Number of Fellows of 5 (as compared with an increase of 27 in 1907, and of 12 in 1906).

The total Number of Fellows is thus increased to 1283, made up as follows:—Compounders, 262 (4 less than in 1907); Contributing Fellows, 994 (13 more than in 1907, and 48 more than in 1906); and Non-Contributing Fellows, 27 (4 less than in 1907).

Turning now to the Lists of Foreign Members and Foreign Correspondents, we have to deplore the loss of three illustrious Foreign Members, Prof. A. de Lapparent, M. A. J. Gaudry, and General J. F. N. Delgado. At the end of 1907 there had remained two vacancies in the List of Foreign Correspondents, which were filled by the election of Dr. Feodor Černyšev and Prof. Hans Schardt into that List; but, at the end of 1908, there were still three vacancies in the List of Foreign Members.

With regard to the Income and Expenditure of the Society during 1908, the figures set forth in detail in the Balance-Sheet may be summarized as follows:—The actual Receipts (excluding the Balance of £168 17*s.* 5*d.* brought forward from the previous year) amounted to £3091 15*s.* 5*d.*, being £41 17*s.* 5*d.* more than the estimated Income. On the other hand, the total Expenditure during the same year amounted to £3062 12*s.* 8*d.*, being £116 5*s.* 4*d.*

less than the estimated Expenditure for the year, and £29 2*s.* 9*d.* less than the actual Receipts, the year closing with a Balance in hand of £198 0*s.* 2*d.*

The Centenary Record, prepared by the Secretary, Prof. W. W. Watts, will be issued to the Fellows within the next few days, and will have as a frontispiece a photogravure portrait of Sir Archibald Geikie, K.C.B., Pres.R.S.

The Council have to announce the completion of Vol. LXIV and the commencement of Vol. LXV of the Society's Quarterly Journal.

The entries regarding British Geology for the year 1906 have been supplied to the Central Bureau of the International Scientific Catalogue, after revision by the Secretary, Prof. Garwood. The question of the manner in which provision is to be made in the future for these entries is one which will no doubt engage the attention of the new Council.

The question of the Admission of Women into the Society having been raised at a Special General Meeting, informal polls were taken, first, of the Fellows resident in the United Kingdom, and then of those resident abroad, the detailed results of which have been published in the Proceedings.

The sixth Award from the Daniel Pidgeon Trust Fund was made on May 20th, 1908, to Mr. James Archibald Douglas, B.A., Demonstrator in Geology in the University of Oxford, who proposed to investigate the zonal succession of the Lower Carboniferous rocks of Western Ireland.

The following Awards of Medals and Funds have also been made by the Council:—

The Wollaston Medal is awarded to Mr. Horace Bolingbroke Woodward, F.R.S., in recognition of researches conducive to the interests of the Sciety in particular and to the science of Geology in general, especially in relation to the Jurassic rocks of Britain and the 'History of the Geological Society.'

The Murchison Medal, together with a sum of Ten Guineas from the Murchison Geological Fund, is awarded to Prof. Grenville A. J. Cole, F.G.S., in recognition of the value of his contributions to Petrology.

The Lyell Medal, together with a sum of Twenty-Five Pounds from the Lyell Geological Fund, is awarded to Prof. Percy Fry Kendall, M.Sc., as a mark of honorary distinction, and as an expression on the part of the Council that he has deserved well of the Science, especially by his researches on the Glacial Geology of England.

The Bigsby Medal is awarded to Dr. John Smith Flett, M.A., as an acknowledgment of the eminent services which he has rendered to Geology, especially by his petrological work, and by his researches concerning the eruption of the Soufrière of St. Vincent.

The Prestwich Medal is awarded to Lady Evans, *in memoriam* of Sir John Evans.

The Balance of the Proceeds of the Wollaston Donation Fund is awarded to Mr. Arthur John Charles Molyneux, F.G.S., in recognition

of his work on the Geology of Rhodesia, and to encourage him in further research.

The Balance of the Proceeds of the Murchison Geological Fund is awarded to Mr. James Vincent Elsden, B.Sc., in acknowledgment of his work among the igneous rocks of Wales, and to encourage him in further research.

A moiety of the Balance of the Proceeds of the Lyell Geological Fund is awarded to Mr. Herbert Brantwood Muff, B.A., in recognition of his researches on the Pleistocene deposits and on the ancient rocks of Scotland and Ireland.

A second moiety of the Balance of the Proceeds of the Lyell Geological Fund is awarded to Mr. Robert George Carruthers, in recognition of his work on the Carboniferous Corals, and to stimulate him to further research.

Report of the Library and Museum Committee for 1908.

The Committee have pleasure in reporting that the Additions made to the Library during the past year have fully maintained, both in number and in importance, the standard of previous years.

During the twelve months under review the Library has received by Donation 234 Volumes of separately-published Works, 329 Pamphlets, 21 Detached Parts of Works, 321 Volumes and 30 Detached Parts of Serial Publications, and 25 Volumes of Newspapers.

The total number of accessions to the Library by Donation is thus found to amount to 580 Volumes, 329 Pamphlets, and 51 Detached Parts. Moreover, 332 Sheets of Geological Maps were presented to the Library, including 17 Folios of the 'Geologic Atlas of the United States'; 208 Sheets received from the Geological Survey of Belgium; 75 Sheets from the Geological Survey of England and Wales, and 15 Sheets from that of Scotland (the majority in both these cases being on the 6-inch scale); 12 Sheets from the Geological Survey of Canada; 10 Sheets from the Austrian Geologische Reichsanstalt; 6 Sheets from the Geological Survey of Japan; 4 Sheets from the Geological Survey of Cape Colony; and 4 Sheets of maps presented by the Swiss Geological Commission.

Among the Books and Pamphlets mentioned in the foregoing paragraph, especial attention may be directed to the following works:—the second part of Vol. II. of Prof. Rosenbusch's new and greatly enlarged edition of the 'Mikroskopische Physiographie der Mineralien & Gesteine'; Prof. J. Walther's 'Geschichte der Erde & des Lebens'; the second volume (Systematic Geology) of Dr. Bailey Willis's 'Research in China'; Dr. J. Gunnar Andersson's 'Contributions to the Geology of the Falkland Islands'; Dr. R. D. M. Verbeek's work on the Geology of the Moluccan Archipelago; sixteen volumes of the 'Bibliographia Geologica' published by the Belgian Geological Survey; Parts III & IV of the monumental work on the Geology of the French Pyrenees, by Prof. L. Carez; Vol. III of the English translation of Prof. Suess's 'Face of the

Earth'; Part II of the third edition of Prof. Kayser's 'Lehrbuch der Geologie'; Dr. J. W. Spencer's work on 'The Falls of Niagara'; Dr. B. N. Peach's monograph on the Higher Crustacea of the Carboniferous Rocks of Scotland: the Geological Survey Memoirs on the neighbourhood of Plymouth & Liskeard, Mevagissey, Oxford, Henley-on-Thames, Andover, the Quantock Hills, and the Small Isles of Inverness-shire; the Palæontology of fifteen counties (from the Victoria History of the Counties of England), by Mr. R. Lydekker. Moreover, thirteen memoirs were presented by the Norwegian Geological Survey, and numerous publications were received from the Geological Survey Departments of Austria, Belgium, France, Hungary, Italy, Prussia. Rumania, Russia, Switzerland, as also from India, Mysore, Canada, the various States of the Australian Commonwealth, New Zealand, the United States, Georgia, Maryland, Illinois, Iowa, New Jersey, New York, Western Virginia, and São Paulo. Among these may be mentioned Prof. T. W. E. David's memoir on the Geology of the Hunter River Coal-Measures (New South Wales); and the late T. Barron's memoir on the Topography & Geology of the Peninsula of Sinai.

The Books and Maps enumerated above were the gift of 140 Government Departments and other Public Bodies: of 179 Societies and Editors of Periodicals; and of 204 Personal Donors.

The Purchases, made on the recommendation of the standing Library Committee, included 48 Volumes and 3 Detached Parts of separately-published Works; 33 Volumes and 2 Parts of Works published serially; and 7 Sheets of Geological Maps.

The Expenditure incurred in connexion with the Library during the Year 1908 was as follows:—

	£	s.	d.
Books, Periodicals, etc. purchased..........	77	19	7
Binding of Books and Mounting of Maps....	140	10	3
	£218	9	10

With regard to the Card-Catalogue of the Library, Mr. C. D. Sherborn reports as follows:—

'The editing of the Card-Catalogue has now reached the letter T. Progress was interrupted in the autumn for two months by the preparation, checking, and sorting-in of the 19,000 cards furnished by the Annual List of Geological Literature received by the Society during 1907.'

Museum.

For the purpose of study and comparison, the Society's Collections were visited on 18 occasions during the year, the contents of 155 drawers being thus examined. The permission of the Council having been duly obtained, about 70 specimens were lent during 1908 to various investigators.

No expenditure has been incurred in connexion with the Museum during the past year.

The appended Lists contain the Names of Government Departments, Public Bodies, Societies, Editors, and Personal Donors, from whom Donations to the Library have been received during the year under review:—

I. Government Departments and other Public Bodies.

Alabama.—Geological Survey. Montgomery (Ala.).
American Museum of Natural History. New York.
Argentina.—Ministerio de Agricultura. Buenos Aires.
Australia (S.), etc. *See* South Australia, *etc.*
Austria.—Kaiserlich-Königliche Geologische Reichsanstalt. Vienna.
Bavaria.—Königliches Bayerisches Oberbergamt. Munich.
Belgium.—Académie Royale des Sciences, des Lettres & Beaux-Arts de Belgique, Brussels.
——. Musée Royal d'Histoire Naturelle. Brussels.
Bergens Museum. Bergen.
Berlin.—Königliche Preussische Akademie der Wissenschaften.
Birmingham, University of.
Bohemia.—Naturwissenschaftliche Landesdurchforschung. Prague.
——. Royal Museum of Natural History. Prague.
Bristol.—Public Library.
British Columbia.—Department of Mines. Victoria (B.C.).
British Guiana.—Department of Mines. Georgetown.
British South Africa Company. London.
Buenos Aires.—Museo Nacional de Buenos Aires.
California.—Academy of Sciences. San Francisco.
——, University of. Berkeley (Cal.).
Camborne.—Mining School.
Cambridge (Mass.).—Museum of Comparative Zoology in Harvard College.
Canada.—Geological & Natural History Survey. Ottawa.
——, High Commissioner for. London.
Cape Colony.—Department of Agriculture (Geological Commission). Cape Town.
——. South African Museum. Cape Town.
Chicago.—'Field' Columbian Museum.
Córdoba (Argentine Republic).—Academía Nacional de Ciencias.
Cracow.—Academy of Sciences.
Denmark.—Commission for Ledelsen af de Geologiske & Geographiske Undersögelser i Grönland. Copenhagen.
——. Kongelige Danske Videnskabernes Selskab. Copenhagen.
Dublin.—Royal Irish Academy.
Egypt.—Department of Public Works (Survey Department). Cairo.
Finland.—Finlands Geologiska Undersökning. Helsingfors.
France.—Ministère des Travaux Publics. Paris.
——. Muséum d'Histoire Naturelle. Paris.
Georgia.—Geological Survey. Atlanta (Ga.).
Germany.—Kaiserliche Leopoldinisch-Carolinische Deutsche Akademie der Naturforscher. Halle an der Saale.
Great Britain.—Army Medical Department. London.
——. British Museum (Natural History). London.
——. Colonial Office. London.
——. Geological Survey. London.
——. Home Office. London.
——. India Office. London.
Holland.—Departement van Kolonien. The Hague.
Hull.—Municipal Museum.
Hungary.—Königliche Ungarische Geologische Anstalt (Magyar Földtani Tarsulat). Budapest.
Illinois State Museum of Natural History. Springfield (Ill.).
India.—Geological Survey. Calcutta.
——. Indian Museum. Calcutta.
——. Surveyor-General's Office. Calcutta.
Iowa Geological Survey. Des Moines (Iowa).
Ireland.—Department of Agriculture & Technical Instruction. Dublin.
Italy.—Reale Comitato Geologico. Rome.

Japan.—Earthquake-Investigation Committee. Tokio.
——. Geological Survey. Tokio.
Jassy, University of.
Kansas.—University Geological Survey. Lawrence (Kan.).
Kingston (Canada).—Queen's College.
Klausenburg (Koloszvár).—Provincial Museum & Library.
London.—City of London College.
——. Imperial Institute.
——. Royal College of Surgeons.
——. University College.
Madrid.—Real Academía de Ciencias Exactes, Físicas & Naturales.
Magdeburg.—Museum für Natur- und Heimatkunde.
Melbourne (Victoria).—National Museum.
Mexico.—Instituto Geológico. Mexico City.
Michigan College of Mines. Houghton (Mich.).
Milan.—Reale Istituto Lombardo di Scienze & Lettere.
Missouri.—Bureau of Geology & Mines. Jefferson City (Mo.).
Montana University. Missoula (Mont.).
Munich.—Königliche Bayerische Akademie der Wissenschaften.
Mysore Geological Department. Bangalore.
Nancy.—Académie de Stanislas.
Naples.—Accademia delle Scienze.
Natal.—Department of Mines. Pietermaritzburg.
——. Geological Survey. Pietermaritzburg.
——. Government Museum. Pietermaritzburg.
Newcastle-upon-Tyne.—Armstrong College.
New Jersey.—Geological Survey. Trentham (N.J.).
New South Wales, Agent-General for. London.
——. Department of Mines & Agriculture. Sydney (N.S.W.).
——. Geological Survey. Sydney (N.S.W.).
New York State Museum. Albany (N.Y.).
New Zealand.—Department of Mines. Wellington (N.Z.).
——. Geological Survey. Wellington (N.Z.).
Norway.—Geological Survey. Christiania.
Nova Scotia.—Department of Mines. Halifax (N.S.).
Ohio Geological Survey. Columbus (Ohio).
Ontario.—Bureau of Mines. Toronto.
Padua.—Reale Accademia di Scienze, Lettere & Arti.
Paris.—Académie des Sciences.
Perak Government. Taiping.
Peru.—Ministerio de Fomento. Lima.
Pisa, Royal University of.
Portugal.—Commissão dos Trabalhos Geologicos. Lisbon.
Prussia.—Ministerium für Handel & Gewerbe. Berlin.
——. Königliche Preussische Geologische Landesanstalt. Berlin.
Queensland, Agent-General for. London.
——. Department of Mines. Brisbane.
——. Geological Survey. Brisbane.
Redruth.—School of Mines.
Rhodesia.—Chamber of Mines. Bulawayo.
Rhodesian Museum. Bulawayo.
Rio de Janeiro.—Museu Nacional.
Rome.—Reale Accademia dei Lincei.
Rumania.—Geological Survey. Bucarest.
Russia.—Comité Géologique. St. Petersburg.
——. Musée Géologique Pierre le Grand. St. Petersburg.
——. Section Géologique du Cabinet de S.M. l'Empereur. St. Petersburg.
São Paulo (Brazil).—Commissão geographica & geologica. São Paulo City.
——. Secretaria da Agricultura, Commercio & Obras Publicas. São Paulo City.
South Australia, Agent-General for. London.
——. Department of Mines. Adelaide.
——. Geological Survey. Adelaide.
Spain.—Comision del Mapa Geológico. Madrid.
Stockholm.—Kongliga Svenska Vetenskaps Akademi.
Sweden.—Sveriges Geologiska Undersökning. Stockholm.
Switzerland.—Geologische Kommission der Schweiz. Berne.
Tasmania.—Secretary for Mines. Hobart.
Tokio.—Imperial University.

Tokio.—College of Science.
Transvaal.—Geological Survey. Pretoria.
——. Mines Department. Pretoria.
Turin.—Reale Accademia delle Scienze.
United States.—Department of Agriculture. Washington (D.C.).
——. Geological Survey. Washington (D.C.).
——. National Museum. Washington (D.C.).
Upsala, University of.
Victoria (Austral.), Agent-General for. London.
—— (——). Department of Mines. Melbourne.
—— (——). Geological Survey. Melbourne.
Vienna.—Kaiserliche Akademie der Wissenschaften.
Washington (D.C.).—Smithsonian Institution.
——, State of (U.S.A.).—Geological Survey. Olympia (Wash.).
West Indies.—Imperial Agricultural Department. Bridgetown (Barbados).
Western Australia, Agent-General for. London.
——. Department of Mines. Perth (W.A.).
——. Geological Survey. Perth (W.A.).
Wisconsin.—Geological & Natural History Survey. Madison (Wisc.).

II. Societies and Editors.

Acireale.—Accademia di Scienze, Lettere & Arti.
Adelaide.—Royal Society of South Australia.
Agram.—Societas Historico-Naturalis Croatica.
Alnwick.—Berwickshire Naturalists' Club.
Basel.—Naturforschende Gesellschaft.
Bath.—Natural History & Antiquarian Field-Club.
Belgrade.—Servian Geological Society.
Bergen.—'Naturen.'
Berlin.—Deutsche Geologische Gesellschaft.
——. Gesellschaft Naturforschender Freunde.
——. 'Zeitschrift für Praktische Geologie.'
Berne.—Schweizerische Naturforschende Gesellschaft.
Bombay Branch of the Royal Asiatic Society.
Bordeaux.—Société Linnéenne.
Boston (Mass.) Society of Natural History.
——. American Academy of Arts & Sciences.
Bristol Naturalists' Society.
Brooklyn (N.Y.) Institute of Arts & Sciences.
Brunswick.—Verein für Naturwissenschaft zu Braunschweig.
Brussels.—Société Belge de Géologie, de Paléontologie & d'Hydrologie.
——. Société Royale Zoologique & Malacologique de Belgique.
Budapest.—Földtani Közlöny.
Buenos Aires.—Sociedad Científica Argentina.
Bulawayo.—Rhodesian Scientific Association.
Caen.—Société Linnéenne de Normandie.
Calcutta.—'Indian Engineering.'
——. Asiatic Society of Bengal.
Cambridge Philosophical Society.
Cape Town.—South African Association for the Advancement of Science.
——. South African Philosophical Society.
Cardiff.—South Wales Institute of Engineers.
Chambéry.—Société d'Histoire Naturelle de Savoie.
Chicago.—'Journal of Geology.'
Christiania.—Norsk Geologisk Forening.
——. 'Nyt Magazin for Naturvidenskaberne.'
Colombo.—Ceylon Branch of the Royal Asiatic Society.
Colorado Springs.—'Colorado College Studies.'
Croydon Natural History & Scientific Society.
Denver.—Colorado Scientific Society.
Dijon.—Académie des Sciences, Arts & Belles-Lettres.
Dorpat (Jurjew).—Naturforschende Gesellschaft.
Dresden.—Naturwissenschaftliche Gesellschaft.
——. Verein für Erdkunde.
Edinburgh.—Geological Society.
——. Royal Scottish Geographical Society.

Edinburgh.—Royal Society.
Ekaterinburg.—Société Ouralienne d'Amateurs des Sciences Naturelles.
Falmouth.—Royal Cornwall Polytechnic Society.
Frankfurt am Main.—Senckenbergische Naturforschende Gesellschaft.
Freiburg im Breisgau.—Naturforschende Gesellschaft.
Fribourg.—Société Fribourgeoise des Sciences Naturelles.
Geneva.—Société de Physique & d'Histoire Naturelle.
Giessen.—Oberhessische Gesellschaft für Natur- & Heilkunde.
Glasgow.—Geological Society.
Gloucester.—Cotteswold Naturalists' Field-Club.
Gratz.—Naturwissenschaftlicher Verein für Steiermark.
Haarlem.—Société Hollandaise des Sciences.
Halifax (N.S.).—Nova Scotian Institute of Science.
Hamilton (Canada).—Hamilton Scientific Association.
Hanau.—Wetterauische Gesellschaft für Gesammte Naturkunde.
Havre.—Société Géologique de Normandie.
Helsingfors.—Société Géographique de Finlande.
Hereford.—Woolhope Naturalists' Field-Club.
Hermannstadt.—Siebenbürgischer Verein für Naturwissenschaft.
Hertford.—Hertfordshire Natural History Society.
Hull.—Geological Society.
——. 'Naturalist'.
Indianapolis (Ind.).—Indiana Academy of Science.
Johannesburg.—Geological Society of South Africa.
Kiev.—Société des Naturalistes.
Lancaster (Pa.).—'Economic Geology.'
Lausanne.—Société Vaudoise des Sciences Naturelles.
Lawrence (Kan.).—'Kansas University Bulletin.'
Leeds.—Geological Association.
——. Philosophical & Literary Society.
——. Yorkshire Geological Society.
Leicester Literary & Philosophical Society.
Leipzig.—'Zeitschrift für Krystallographie & Mineralogie.'
Liége.—Société Géologique de Belgique.
——. Société Royale des Sciences.
Lille.—Société Géologique du Nord.
Lima.—'Revista de Ciencias.'
Lisbon.—Sociedade de Geographia.
Liverpool Geological Society.
——. Literary & Philosophical Society.
London.—'The Athenæum.'
——. British Association for the Advancement of Science.
——. British Association of Waterworks Engineers.
——. Chemical Society.
——. 'The Chemical News.'
——. 'The Colliery Guardian.'
——. 'The Geological Magazine.'
——. Geologists' Association.
——. Institution of Civil Engineers.
——. Institution of Mining Engineers.
——. Institution of Mining & Metallurgy.
——. Iron & Steel Institute.
——. Linnean Society.
——. 'The London, Edinburgh, & Dublin Philosophical Magazine.'
——. Mineralogical Society.
——. 'The Mining Journal.'
——. 'Nature.'
——. Palæontographical Society.
——. 'The Quarry.'
——. Ray Society.
——. 'Records of the London & West-Country Chamber of Mines.'
——. Royal Geographical Society.
——. Royal Institution.
——. Royal Meteorological Society.
——. Royal Microscopical Society.
——. Royal Photographic Society.
——. Royal Society.
——. Royal Society of Arts.

London.—Society of Biblical Archæology.
——. 'The South-Eastern Naturalist' (S.E. Union of Scientific Societies).
——. Victoria Institute.
——. 'Water.'
——. Zoological Society.
Manchester Geological & Mining Society.
——. Literary & Philosophical Society.
Manila.—Philippine Journal of Science.
Melbourne (Victoria).—Australasian Institute of Mining Engineers.
——. Royal Society of Victoria.
——. 'The Victorian Naturalist.'
Mexico.—Sociedad Científica 'Antonio Alzate.'
Moscow.—Société Impériale des Naturalistes.
New Haven (Conn.).—'The American Journal of Science.'
New York.—Academy of Sciences.
——. American Institute of Mining Engineers.
——. 'Science.'
Newcastle-upon-Tyne.—North of England Institute of Mining & Mechanical Engineers.
——. University of Durham Philosophical Society.
Northampton.—Northamptonshire Natural History Society.
Nürnberg.—Naturhistorische Gesellschaft.
Oporto.—Academia Polytecnica. [Coimbra.]
Ottawa.—Royal Society of Canada.
Paris.—Commission Française des Glaciers.
——. Société Française de Minéralogie.
——. Société Géologique de France.
——. 'Spelunca.'
Penzance.—Royal Geological Society of Cornwall.
Perth.—Perthshire Society of Natural Science.
Philadelphia.—Academy of Natural Sciences.
——. American Philosophical Society.
Pisa.—Società Toscana di Scienze Naturali.
Plymouth.—Devonshire Association for the Advancement of Science.
Rennes.—Société Scientifique & Médicale de l'Ouest.
Rochester (N.Y.).—Academy of Science.
——. Geological Society of America.
Rome.—Società Geologica Italiana.
Rugby School Natural History Society.
Santiago de Chile.—Sociedad Nacional de Minería.
——. Société Scientifique du Chili.
São Paulo (Brazil).—Sociedade Scientifica.
Scranton (Pa.).—'Mines & Minerals.'
St. John (N.B.).—Natural History Society of New Brunswick.
St. Petersburg.—Russische Kaiserliche Mineralogische Gesellschaft.
Stockholm.—Geologiska Förening.
Stratford.—Essex Field-Club.
Stuttgart.—'Centralblatt für Mineralogie, Geologie & Paläontologie.'
——. 'Neues Jahrbuch für Mineralogie, Geologie & Paläontologie.'
——. Oberrheinischer Geologischer Verein.
——. Verein für Vaterländische Naturkunde in Württemberg.
——. 'Zeitschrift für Naturwissenschaften.'
Sydney (N.S.W.).—Linnean Society of New South Wales.
——. Royal Society of New South Wales.
Toronto.—Canadian Institute.
Toulouse.—Société d'Histoire Naturelle.
Truro.—Royal Institution of Cornwall.
Vienna.—'Beiträge zur Paläontologie & Geologie Œsterreich-Ungarns & des Orients.'
——. 'Berg- & Hüttenmännisches Jahrbuch.'
——. Geologische Gesellschaft.
——. Kaiserlich-Königliche Zoologisch-Botanische Gesellschaft.
Washington (D.C.).—Academy of Sciences.
——. Biological Society.
——. Philosophical Society.
Wellington (N.Z.).—New Zealand Institute.
Wiesbaden.—Nassauischer Verein für Naturkunde.
York.—Yorkshire Philosophical Society.

III. Personal Donors.

Abbot, C. G.
Allen, E. T.
Anderson, R.
Andrews, C.
Arber, E. A. N.
Arnold, R.
Avebury, Lord.

Bailey, E. B.
Bailey, S. B.
Bain, H. F.
Barrow, G.
Basedow, H.
Beadnell, H. J. L.
Bennett, F. J.
Bickel, W.
Blache, J. V. de la.
Blake, W. P.
Bonney, T. G.
Borredon, G.
Branca, W.
Branner, J. C.
Breton, L.
Brown, H. Y. L.
Buchanan, J. J.
Buckman, S. S.
Burton, F. M.
Buxtorf, A.

Cantrill, T. C.
Carey, A. E.
Carez, L.
Chapman, E. J.
Chapman, F.
Clement, J. K.
Clough, C. T.
Cockerell, T. D. A.
Cole, G. A. J.
Comstock, C. W.
Corstorphine, G. S.
Crick, G. C.
Crook, C. V.

Dall, W. H.
Daly, R. A.
David, T. W. E.
Davies, J. S.
Davies, M.
Davis, W. M.
Delgado, J. F. N.
Dewey, H.
Dixon, E. E. L.
Dœlter, C.
Dolé, L.
Dollfus, G. F.
Duparc, L.

Egglestone, W. M.
Eriksson, A. B.
Evans, J. W.
Evans, Sir John.

Flett, J. S.
Fox, H.
Fowle, F. E., jun.
Fraipont, C.
Fritsch, A.

Gagel, C.
Gaudry, A.
Gentil, L.
Gibson, W.
Gilbert, G. K.
Goodchild, W.
Gosselet, J.
Gourdon, E.
Green, U.
Guppy, R. J. L.

Harbort, E.
Harrison, W. J.
Hatch, F. H.
Hayden, H. H.
Headden, W. P.
Heim, A.
Heusch, H.
Hill, R. T.
Hind, W.
Hinde, G. J.
Hjort, J.
Hogg, A. J.
Holland, P.
Hopkinson, J.
Hubert, H.
Hull, E.
Hunter, T. G.

James, W.
Johannsen, A.
Johnson, J. P.
Johnston-Lavis, H. J.
Jordan, D. S.
Jorissen, E.
Jukes-Browne, A. J.

Kayser, E.
Kendall, P. F.
Kirsopp, J.
Knott, C. G.
Koch, W. E.
Kœhler, R.
Kruckenberg, I.

Lacroix, A.
Lambe, L. M.
Lempfert, R. G. H.
Lobley, J. L.
Lowe, H. J.
Lull, R. S.
Lydekker, R.
Lyons, H. G.

MacAlister, D. A.
Maclaren, J. M.
Maitland, A. G.
Manson, M.
Martin, E. A.
Matley, C. A.
Mennell, F. P.
Metcalfe, A. T.
Mill, H. R.
Monckton, H. W.
Murray, Sir John.

Nacken, R.
Nares, Sir George.
Nathorst, A. G.
Neumann, C.
Newton, E. T.
Newton, R. B.

Oliver, F.

Parkinson, J.
Parsons, J.
Pearce, F.
Pervinquière, L.
Pjetursson, H.

Reade, T. M.
Reed, F. R. C.
Reid, C.
Reid (Mrs.), E. M.
Riccardo, L.
Richardson, L.
Rigaux, E.
Rowe, A. W.
Rye, A.

Sacco, F.
Salter, A. E.
Sandberg, C. G. S.
Sargant (Miss), E.
Sawyer, A. R.
Schæberle, J. M.
Schardt, H.
Schwarz, E. H. L.
Sederholm, J. J.
See, T. J. J.
Serretta, F.
Seward, A. C.
Sheppard, T.
Sherborn, C. D.
Skeats, E. W.
Smith, G. F. H.
Smith, J.
Smith, W. D.
Somervail, A.
Sommerfeldt, E.
Spencer, J. W.
Spencer, L. J.
Spencer, W.
Stanley, W. F.
Stather, J. W.
Stefanescu, G. R.
Stevenson, J. J.
Steward, J. H.
Stobbs, J. T.
Stuart-Menteath, P. W.
Style, A. H.

Suess, E.
Sury, J. von.

Tassin, W.
Termier, P.
Thackeray, F. St. J.
Tietze, E.
Törnquist, S. L.

Uhlig, V.

Vallentine, E. J.
Vaney, C.
Vaughan, A.
Verbeek, R. D. M.

Walker, H.
Walther, J.
Whitaker, W.
Wieland, G. R.
Wilckens, O.
Williams, H. S.
Williston, S. W.
Woodward, A. S.
Woodward, H.
Woodward, H. B.
Woolacott, D.
Worth, R. H.
Wright, F. E.
Wright, G. F.

Young, A. P.
Young, R. B.
York, William, Archbishop of.

Zeil, G.

Comparative Statement of the Number of the Society at the Close of the Years 1907 and 1908.

	Dec. 31st, 1907.		Dec. 31st, 1908.
Compounders	266	......	262
Contributing Fellows......	981	......	994
Non-Contributing Fellows..	31	......	27
	1278		1283
Foreign Members	40	......	37
Foreign Correspondents....	38	......	40
	1356		1360

Comparative Statement, explanatory of the Alterations in the Number of Fellows, Foreign Members, and Foreign Correspondents at the close of the years 1907 and 1908.

Number of Compounders, Contributing and Non-Contributing Fellows, December 31st, 1907 ..			1278
Add Fellows elected during the former year and paid in 1908			15
Add Fellows elected and paid in 1908			37
			1330
Deduct Compounders deceased................		7	
Contributing Fellows deceased		11	
Non-Contributing Fellows deceased		4	
Contributing Fellows resigned		21	
Contributing Fellows removed		4	
		—	47
			1283
Number of Foreign Members and Foreign Correspondents, December 31st, 1907		78	
Deduct Foreign Members deceased	3		
	—	3	
		75	
Add Foreign Correspondents elected	2		
	—	2	
		—	77
			1360

Deceased Fellows.

Compounders (7).

Hambley, E. B. C.
Howitt, Dr. A. W.
Ince, J.
James, J. W.
Mangles, H. A.
Parkyn, Major E.
Stirling, J.

Resident and other Contributing Fellows (11).

Addison, P. L.
Bradford, J.
Brough, B. H.
Groves, J.
Harrington, Prof. B. J.
Harrison, W. J.
Law, R.
Player, J. H.
Squire, J. B.
Strachey, Sir Richard.
Thomas, Arnold.

Non-Contributing Fellows (4).

Cavell, E.
Evans, Sir John.
Norwood, Rev. T. W.
Sorby, Dr. H. C.

Deceased Foreign Members (3).

Delgado, General J. F. N.
Gaudry, Prof. A. J.
Lapparent, Prof. A. A. de.

Fellows Resigned (21).

Berkeley, Earl of.
Blaker, C. E.
Brend, W. A.
Bufton, Rev. J.
Burstal, E. K.
Hannah, R.
Holroyd, W. F.
Humphrey, Dr. W. A.
Husband, J.
Jones, Rev. E.
Joyce, T. W.
Kent, Prof. A. F. S.
Kirchhoffer, S. G.
Lailey, C. N.
Matthews, W.
Page, D.
Pollen, Commander F. H.
Preston, A. E.
Robinson, J.
Tyzack, D.
Wollemann, Dr. A.

Fellows Removed (4).

Lardeur, A. E.
Moss-Flower, T. J.
Ogilvie, A. G.
Oxley-Oxland, B. M.

The following Personages were elected Foreign Correspondents during the year 1908 :—

Dr. Feodor Černyšev, of St. Petersburg.
Prof. Hans Schardt, of Veytaux.

After the Reports had been read, it was resolved :—

That they be received and entered on the Minutes of the Meeting, and that such parts of them as the Council shall think fit be printed and circulated among the Fellows.

It was afterwards resolved :—

That the thanks of the Society be given to Mr. F. W. Rudler, Dr. A. Strahan, and Dr. A. Smith Woodward, retiring from the office of Vice-President.

That the thanks of the Society be given to Prof. W. W. Watts, retiring from the office of Secretary.

That the thanks of the Society be given to Mr. H. W. Monckton, retiring from the office of Treasurer.

That the thanks of the Society be given to Mr. R. Lydekker, Principal H. A. Miers, Mr. F. W. Rudler, Mr. L. J. Spencer, and Mr. C. Fox Strangways, retiring from the Council.

After the Balloting-Glasses had been closed, and the Lists examined by the Scrutineers, the following gentlemen were declared to have been duly elected as the Officers and Council for the ensuing year :—

OFFICERS AND COUNCIL.—1909.

PRESIDENT.

Prof. William Johnson Sollas, LL.D., Sc.D., F.R.S.

VICE-PRESIDENTS.

George William Lamplugh, F.R.S.
Horace Woollaston Monckton, Treas.L.S.
J. J. Harris Teall, M.A., D.Sc., F.R.S.
Prof. William Whitehead Watts, Sc.D., M.Sc., F.R.S.

SECRETARIES.

Prof. Edmund Johnston Garwood, M.A.
Arthur Smith Woodward, LL.D., F.R.S., F.L.S.

FOREIGN SECRETARY.

Sir Archibald Geikie, K.C.B., D.C.L., LL.D., Sc.D., Pres.R.S.

TREASURER.

Aubrey Strahan, Sc.D., F.R.S.

COUNCIL.

Charles William Andrews, B.A., D.Sc., F.R.S.
George Barrow.
Prof. William S. Boulton, B.Sc.
Prof. Samuel Herbert Cox, F.C.S., Assoc.R.S.M.
Prof. Edmund Johnston Garwood, M.A.
Sir Archibald Geikie, K.C.B., D.C.L., LL.D., Sc.D., Pres.R.S.
Alfred Harker, M.A., F.R.S.
Robert Stansfield Herries, M.A.
Finlay Lorimer Kitchin, M.A., Ph.D.
George William Lamplugh, F.R.S.
John Edward Marr, Sc.D., F.R.S.
Horace Woollaston Monckton, Treas.L.S.
Richard Dixon Oldham.
George Thurland Prior, M.A., D.Sc.
Prof. Sidney Hugh Reynolds, M.A.
Prof. William Johnson Sollas, LL.D., Sc.D., F.R.S.
Aubrey Strahan, Sc.D., F.R.S.
J. J. Harris Teall, M.A., D.Sc., F.R.S.
Richard Hill Tiddeman, M.A.
Prof. William Whitehead Watts, Sc.D., M.Sc., F.R.S.
Henry Woods, M.A.
Arthur Smith Woodward, LL.D., F.R.S., F.L.S.
George William Young.

LIST OF

THE FOREIGN MEMBERS

OF THE GEOLOGICAL SOCIETY OF LONDON, IN 1908.

Date of Election.

1874. Prof. Albert Jean Gaudry, *Paris.* (*Deceased.*)
1877. Prof. Eduard Suess, *Vienna.*
1880. Geheimrath Prof. Ferdinand Zirkel, *Leipzig.*
1884. Commendatore Prof. Giovanni Capellini, *Bologna.*
1885. Prof. Jules Gosselet, *Lille.*
1886. Prof. Gustav Tschermak, *Vienna.*
1890. Geheimrath Prof. Heinrich Rosenbusch, *Heidelberg.*
1891. Prof. Charles Barrois, *Lille.*
1893. Prof. Waldemar Christofer Brœgger, *Christiania.*
1893. M. Auguste Michel-Lévy, *Paris.*
1893. Prof. Alfred Gabriel Nathorst, *Stockholm.*
1894. Prof. George J. Brush, *New Haven, Conn.* (*U.S.A.*).
1894. Prof. Edward Salisbury Dana, *New Haven, Conn.* (*U.S.A.*).
1895. Dr. Grove Karl Gilbert, *Washington, D.C.* (*U.S.A.*).
1895. Dr. Friedrich Schmidt, *St. Petersburg.* (*Deceased.*)
1896. Prof. Albert Heim, *Zürich.*
1897. M. Édouard Dupont, *Brussels.*
1897. Dr. Anton Fritsch, *Prague.*
1897. Dr. Hans Reusch, *Christiania.*
1898. Geheimrath Prof. Hermann Credner, *Leipzig.*
1898. Dr. Charles Doolittle Walcott, *Washington, D.C.* (*U.S.A.*).
1899. General Joaquim Felipe Nery Delgado, *Lisbon.* (*Deceased.*)
1899. Prof. Emanuel Kayser, *Marburg.*
1899. M. Ernest Van den Broeck, *Brussels.*
1899. Dr. Charles Abiathar White, *Washington, D.C.* (*U.S.A.*).
1900. M. Gustave F. Dollfus, *Paris.*
1900. Prof. Paul von Groth, *Munich.*
1900. Dr. Sven Leonhard Tœrnquist, *Lund.*
1901. M. Alexander Petrovich Karpinsky, *St. Petersburg.*
1901. Prof. Alfred Lacroix, *Paris.*
1903. Prof. Albrecht Penck, *Berlin.*
1903. Prof. Anton Koch, *Budapest.*
1904. Prof. Joseph Paxson Iddings, *Chicago* (*U.S.A.*).
1904. Prof. Henry Fairfield Osborn, *New York* (*U.S.A.*).
1905. Prof. Louis Dollo, *Brussels.*
1905. Prof. August Rothpletz, *Munich.*
1906. Prof. Count Hermann zu Solms-Laubach, *Strasburg.*
1907. Hofrath Dr. Emil Ernst August Tietze, *Vienna.*
1907. Commendatore Prof. Arturo Issel, *Genoa.*

LIST OF
THE FOREIGN CORRESPONDENTS
OF THE GEOLOGICAL SOCIETY OF LONDON, IN 1908.

Date of Election.

1874. Prof. Igino Cocchi, *Florence.*
1879. Dr. H. Émile Sauvage, *Boulogne-sur-Mer.*
1889. Dr. Rogier Diederik Marius Verbeek, *The Hague.*
1890. Geheimer Bergrath Prof. Adolph von Kœnen, *Göttingen.*
1892. Prof. Johann Lehmann, *Kiel.*
1893. Prof. Aléxis P. Pavlow, *Moscow.*
1893. M. Ed. Rigaux, *Boulogne-sur-Mer.*
1894. M. Louis Perceval de Loriol-Le Fort, *Campagne Frontenex, near Geneva.* (*Deceased.*)
1894. Dr. Francisco P. Moreno, *La Plata.*
1894. Prof. Johan H. L. Vogt, *Christiania.*
1895. Prof. Constantin de Kroustchoff, *St. Petersburg.*
1896. Prof. Johannes Walther, *Halle an der Saale.*
1897. M. Emmanuel de Margerie, *Paris.*
1898. Dr. Marcellin Boule, *Paris.*
1898. Dr. W. H. Dall, *Washington, D.C.* (*U.S.A.*).
1899. Dr. Gerhard Holm, *Stockholm.*
1899. Prof. Theodor Liebisch, *Göttingen.*
1899. Prof. Franz Lœwinson-Lessing, *St. Petersburg.*
1899. M. Michel F. Mourlon, *Brussels.*
1899. Prof. Gregorio Stefanescu, *Bucarest.*
1899. Prof. René Zeiller, *Paris.*
1900. Prof. Ernst Koken, *Tübingen.*
1900. Prof. Federico Sacco, *Turin.*
1901. Prof. Friedrich Johann Becke, *Vienna.*
1902. Prof. Thomas Chrowder Chamberlin, *Chicago, Ill.* (*U.S.A.*).
1902. Dr. Thorvaldr Thoroddsen, *Copenhagen.*
1902. Prof. Samuel Wendell Williston, *Chicago, Ill.* (*U.S.A.*).
1904. Dr. William Bullock Clark, *Baltimore* (*U.S.A.*).
1904. Dr. Erich Dagobert von Drygalski, *Charlottenburg.*
1904. Prof. Giuseppe de Lorenzo, *Naples.*
1904. The Hon. Frank Springer, *Burlington, Iowa* (*U.S.A.*).
1904. Dr. Henry S. Washington, *Locust, N.J.* (*U.S.A.*).
1905. Prof. Bundjirô Kôtô, *Tokyo.*
1906. Prof. John M. Clarke, *Albany, N.Y.* (*U.S.A.*).
1906. Prof. William Morris Davis, *Cambridge, Mass.* (*U.S.A.*).
1906. Dr. Jakob Johannes Sederholm, *Helsingfors.*
1907. Prof. Baron Gerard Jakob de Geer, *Stockholm.*
1907. Prof. Armin Baltzer, *Berne.*
1908. Dr. Feodor Černyšev, *St. Petersburg.*
1908. Prof. Hans Schardt, *Veytaux, near Montreux*

AWARDS OF THE WOLLASTON MEDAL

UNDER THE CONDITIONS OF THE 'DONATION FUND'

ESTABLISHED BY

WILLIAM HYDE WOLLASTON, M.D., F.R.S., F.G.S., ETC.

'To promote researches concerning the mineral structure of the Earth, and to enable the Council of the Geological Society to reward those individuals of any country by whom such researches may hereafter be made,'—'such individual not being a Member of the Council.'

1831. Mr. William Smith.
1835. Dr. Gideon A. Mantell.
1836. M. Louis Agassiz.
1837. { Capt. T. P. Cautley. / Dr. Hugh Falconer. }
1838. Sir Richard Owen.
1839. Prof. C. G. Ehrenberg.
1840. Prof. A. H. Dumont.
1841. M. Adolphe T. Brongniart.
1842. Baron Leopold von Buch.
1843. { M. Élie de Beaumont. / M. P. A. Dufrénoy. }
1844. The Rev. W. D. Conybeare.
1845. Prof. John Phillips.
1846. Mr. William Lonsdale.
1847. Dr. Ami Boué.
1848. The Very Rev. W. Buckland.
1849. Sir Joseph Prestwich.
1850. Mr. William Hopkins.
1851. The Rev. Prof. A. Sedgwick.
1852. Dr. W. H. Fitton.
1853. { M. le Vicomte A. d'Archiac. / M. E. de Verneuil. }
1854. Sir Richard Griffith.
1855. Sir Henry De la Beche.
1856. Sir William Logan.
1857. M. Joachim Barrande.
1858. { Herr Hermann von Meyer. / Prof. James Hall. }
1859. Mr. Charles Darwin.
1860. Mr. Searles V. Wood.
1861. Prof. Dr. H. G. Bronn.
1862. Mr. R. A. C. Godwin-Austen.
1863. Prof. Gustav Bischof.
1864. Sir Roderick Murchison.
1865. Dr. Thomas Davidson.
1866. Sir Charles Lyell.
1867. Mr. G. Poulett Scrope.
1868. Prof. Carl F. Naumann.
1869. Dr. Henry C. Sorby.
1870. Prof. G. P. Deshayes.
1871. Sir Andrew Ramsay.
1872. Prof. James D. Dana.
1873. Sir P. de M. Grey Egerton.
1874. Prof. Oswald Heer.
1875. Prof. L. G. de Koninck.
1876. Prof. Thomas H. Huxley.
1877. Mr. Robert Mallet.
1878. Dr. Thomas Wright.
1879. Prof. Bernhard Studer.
1880. Prof. Auguste Daubrée.
1881. Prof. P. Martin Duncan.
1882. Dr. Franz Ritter von Hauer.
1883. Dr. William Thomas Blanford.
1884. Prof. Albert Jean Gaudry.
1885. Mr. George Busk.
1886. Prof. A. L. O. Des Cloizeaux.
1887. Mr. John Whitaker Hulke.
1888. Mr. Henry B. Medlicott.
1889. Prof. Thomas George Bonney.
1890. Prof. W. C. Williamson.
1891. Prof. John Wesley Judd.
1892. Baron F. von Richthofen.
1893. Prof. Nevil Story Maskelyne.
1894. Prof. Karl Alfred von Zittel.
1895. Sir Archibald Geikie
1896. Prof. Eduard Suess.
1897. Mr. Wilfrid H. Hudleston.
1898. Prof. Ferdinand Zirkel.
1899. Prof. Charles Lapworth.
1900. Dr. Grove Karl Gilbert.
1901. Prof. Charles Barrois.
1902. Dr. Friedrich Schmidt.
1903. Prof. Heinrich Rosenbusch.
1904. Prof. Albert Heim.
1905. Dr. J. J. Harris Teall.
1906. Dr. Henry Woodward.
1907. Prof. William Johnson Sollas.
1908. Prof. Paul von Groth.
1909. Mr. Horace B. Woodward.

AWARDS

OF THE

BALANCE OF THE PROCEEDS OF THE WOLLASTON 'DONATION FUND.'

1831. Mr. William Smith.
1833. Mr. William Lonsdale.
1834. M. Louis Agassiz.
1835. Dr. Gideon A. Mantell.
1836. Prof. G. P. Deshayes.
1838. Sir Richard Owen.
1839. Prof. C. G. Ehrenberg.
1840. Mr. J. De Carle Sowerby.
1841. Prof. Edward Forbes.
1842. Prof. John Morris.
1843. Prof. John Morris.
1844. Mr. William Lonsdale.
1845. Mr. Geddes Bain.
1846. Mr. William Lonsdale.
1847. M. Alcide d'Orbigny.
1848. { Cape of Good Hope Fossils. M. Alcide d'Orbigny. }
1849. Mr. William Lonsdale.
1850. Prof. John Morris.
1851. M. Joachim Barrande.
1852. Prof. John Morris.
1853. Prof. L. G. de Koninck.
1854. Dr. Samuel P. Woodward.
1855. Drs. G. and F. Sandberger.
1856. Prof. G. P. Deshayes.
1857. Dr. Samuel P. Woodward.
1858. Prof. James Hall.
1859. Mr. Charles Peach.
1860. { Prof. T. Rupert Jones. Mr. W. K. Parker. }
1861. Prof. Auguste Daubrée.
1862. Prof. Oswald Heer.
1863. Prof. Ferdinand Senft.
1864. Prof. G. P. Deshayes.
1865. Mr. J. W. Salter.
1866. Dr. Henry Woodward.
1867. Mr. W. H. Baily.
1868. M. J. Bosquet.
1869. Dr. William Carruthers.
1870. M. Marie Rouault.
1871. Mr. Robert Etheridge.
1872. Dr. James Croll.
1873. Prof. John Wesley Judd.
1874. Dr. Henri Nyst.
1875. Prof. Louis C. Miall.
1876. Prof. Giuseppe Seguenza.
1877. Mr. Robert Etheridge, Jun.
1878. Prof. William Johnson Sollas.
1879. Mr. Samuel Allport.
1880. Mr. Thomas Davies.
1881. Dr. Ramsay Heatley Traquair.
1882. Dr. George Jennings Hinde.
1883. Prof. John Milne.
1884. Mr. Edwin Tulley Newton.
1885. Dr. Charles Callaway.
1886. Mr. J. Starkie Gardner.
1887. Dr. Benjamin Neeve Peach.
1888. Dr. John Horne.
1889. Dr. Arthur Smith Woodward.
1890. Mr. William A. E. Ussher.
1891. Mr. Richard Lydekker.
1892. Mr. Orville Adelbert Derby.
1893. Mr. John George Goodchild.
1894. Dr. Aubrey Strahan.
1895. Prof. William W. Watts.
1896. Mr. Alfred Harker.
1897. Dr. Francis Arthur Bather.
1898. Prof. Edmund J. Garwood.
1899. Prof. John B. Harrison.
1900. Dr. George Thurland Prior.
1901. Mr. Arthur Walton Rowe.
1902. Mr. Leonard James Spencer.
1903. Mr. L. L. Belinfante.
1904. Miss Ethel M. R. Wood.
1905. Dr. H. H. Arnold-Bemrose.
1906. Dr. Finlay Lorimer Kitchin.
1907. Dr. Arthur Vaughan.
1908. Mr. Herbert Henry Thomas.
1909. Mr. Arthur J. C. Molyneux.

AWARDS OF THE MURCHISON MEDAL

UNDER THE CONDITIONS OF THE

'MURCHISON GEOLOGICAL FUND,'

ESTABLISHED UNDER THE WILL OF THE LATE

SIR RODERICK IMPEY MURCHISON, Bart., F.R.S., F.G.S.

'To be applied in every consecutive year, in such manner as the Council of the Society may deem most useful in advancing Geological Science, whether by granting sums of money to travellers in pursuit of knowledge, to authors of memoirs, or to persons actually employed in any enquiries bearing upon the science of Geology, or in rewarding any such travellers, authors, or other persons, and the Medal to be given to some person to whom such Council shall grant any sum of money or recompense in respect of Geological Science.'

1873. Mr. William Davies.
1874. Dr. J. J. Bigsby.
1875. Mr. W. J. Henwood.
1876. Mr. Alfred R. C. Selwyn.
1877. The Rev. W. B. Clarke.
1878. Prof. Hanns Bruno Geinitz.
1879. Sir Frederick M'Coy.
1880. Mr. Robert Etheridge.
1881. Sir Archibald Geikie.
1882. Prof. Jules Gosselet.
1883. Prof. H. R. Gœppert.
1884. Dr. Henry Woodward.
1885. Dr. Ferdinand von Rœmer.
1886. Mr. William Whitaker.
1887. The Rev. Peter B. Brodie.
1888. Prof. J. S. Newberry.
1889. Prof. James Geikie.
1890. Prof. Edward Hull.
1891. Prof. Waldemar C. Brœgger.
1892. Prof. A. H. Green.
1893. The Rev. Osmond Fisher.
1894. Mr. William T. Aveline.
1895. Prof. Gustaf Lindstrœm.
1896. Mr. T. Mellard Reade.
1897. Mr. Horace B. Woodward.
1898. Mr. Thomas F. Jamieson.
1899. { Dr. Benjamin N. Peach. / Dr. John Horne.
1900. Baron A. E. Nordenskiœld.
1901. Mr. A. J. Jukes-Browne.
1902. Mr. Frederic W. Harmer.
1903. Dr. Charles Callaway.
1904. Prof. George A. Lebour.
1905. Mr. Edward John Dunn.
1906. Mr. Charles T. Clough.
1907. Mr. Alfred Harker.
1908. Prof. Albert Charles Seward.
1909. Prof. Grenville A. J. Cole.

AWARDS

OF THE

BALANCE OF THE PROCEEDS OF THE 'MURCHISON GEOLOGICAL FUND.'

1873. Prof. Oswald Heer.
1874. Mr. Alfred Bell.
1874. Prof. Ralph Tate.
1875. Prof. H. Govier Seeley.
1876. Dr. James Croll.
1877. The Rev. John F. Blake.
1878. Prof. Charles Lapworth.
1879. Mr. James Walker Kirkby.
1880. Mr. Robert Etheridge.
1881. Mr. Frank Rutley.
1882. Prof. Thomas Rupert Jones.
1883. Dr. John Young.
1884. Mr. Martin Simpson.
1885. Mr. Horace B. Woodward.
1886. Mr. Clement Reid.
1887. Dr. Robert Kidston.
1888. Mr. Edward Wilson.
1889. Prof. Grenville A. J. Cole.
1890. Mr. Edward B. Wethered.
1891. The Rev. Richard Baron.
1892. Mr. Beeby Thompson.
1893. Mr. Griffith John Williams.
1894. Mr. George Barrow.
1895. Prof. Albert Charles Seward.
1896. Mr. Philip Lake.
1897. Mr. Sydney S. Buckman.
1898. Miss Jane Donald.
1899. Mr. James Bennie.
1900. Mr. A. Vaughan Jennings.
1901. Mr. Thomas S. Hall.
1902. Sir Thomas H. Holland.
1903. Mrs. Elizabeth Gray.
1904. Dr. Arthur Hutchinson.
1905. Mr. Herbert Lister Bowman.
1906. Dr. Herbert Lapworth.
1907. Dr. Felix Oswald.
1908. Miss Ethel Gertrude Skeat.
1909. Mr. James Vincent Elsden.

AWARDS OF THE LYELL MEDAL

UNDER THE CONDITIONS OF THE

'LYELL GEOLOGICAL FUND,'

ESTABLISHED UNDER THE WILL AND CODICIL OF THE LATE

SIR CHARLES LYELL, Bart., F.R.S., F.G.S.

The Medal 'to be cast in bronze and to be given annually' (or from time to time) 'as a mark of honorary distinction and as an expression on the part of the governing body of the Society that the Medallist (who may be of any country or either sex) has deserved well of the Science,'—'not less than one third of the annual interest [of the fund] to accompany the Medal, the remaining interest to be given in one or more portions, at the discretion of the Council, for the encouragement of Geology or of any of the allied sciences by which they shall consider Geology to have been most materially advanced, either for travelling expenses or for a memoir or paper published, or in progress, and without reference to the sex or nationality of the author, or the language in which any such memoir or paper may be written.'

There is a further provision for suspending the award for one year, and in such case for the awarding of a Medal to 'each of two persons who have been jointly engaged in the same exploration in the same country, or perhaps on allied subjects in different countries, the proportion of interest always not being less to each Medal than one third of the annual interest.'

1876. Prof. John Morris.
1877. Sir James Hector.
1878. Mr. George Busk.
1879. Prof. Edmond Hébert.
1880. Sir John Evans.
1881. Sir J. William Dawson.
1882. Dr. J. Lycett.
1883. Dr. W. B. Carpenter.
1884. Dr. Joseph Leidy.
1885. Prof. H. Govier Seeley.
1886. Mr. William Pengelly.
1887. Mr. Samuel Allport.
1888. Prof. Henry A. Nicholson.
1889. Prof. W. Boyd Dawkins.
1890. Prof. Thomas Rupert Jones.
1891. Prof. T. McKenny Hughes.
1892. Mr. George H. Morton.
1893. Mr. Edwin Tulley Newton.
1894. Prof. John Milne.
1895. The Rev. John F. Blake.
1896. Dr. Arthur Smith Woodward.
1897. Dr. George Jennings Hinde.
1898. Prof. Wilhelm Waagen.
1899. Lt.-Gen. C. A. McMahon.
1900. Dr. John Edward Marr.
1901. Dr. Ramsay Heatley Traquair.
1902. { Prof. Anton Fritsch.
Mr. Richard Lydekker.
1903. Mr. Frederick William Rudler.
1904. Prof. Alfred Gabriel Nathorst.
1905. Dr. Hans Reusch.
1906. Prof. Frank Dawson Adams.
1907. Dr. Joseph F. Whiteaves.
1908. Mr. Richard Dixon Oldham.
1909. Prof. Percy Fry Kendall.

AWARDS

OF THE

BALANCE OF THE PROCEEDS OF THE 'LYELL GEOLOGICAL FUND.'

1876. Prof. John Morris.
1877. Mr. William Pengelly.
1878. Prof. Wilhelm Waagen.
1879. Prof. Henry A. Nicholson.
1879. Dr. Henry Woodward.
1880. Prof. F. A. von Quenstedt.
1881. Prof. Anton Fritsch.
1881. Mr. G. R. Vine.
1882. The Rev. Norman Glass.
1882. Prof. Charles Lapworth.
1883. Mr. P. H. Carpenter.
1883. M. Ed. Rigaux.
1884. Prof. Charles Lapworth.
1885. Mr. Alfred J. Jukes-Browne.
1886. Mr. David Mackintosh.
1887. The Rev. Osmond Fisher.
1888. Dr. Arthur H. Foord.
1888. Mr. Thomas Roberts.
1889. Dr. Louis Dollo.
1890. Mr. Charles Davies Sherborn.
1891. Dr. C. I. Forsyth Major.
1891. Mr. George W. Lamplugh.
1892. Prof. John Walter Gregory.
1892. Mr. Edwin A. Walford.
1893. Miss Catherine A. Raisin.
1893. Mr. Alfred N. Leeds.
1894. Mr. William Hill.
1895. Prof. Percy Fry Kendall.
1895. Mr. Benjamin Harrison.
1896. Dr. William F. Hume.
1896. Dr. Charles W. Andrews.
1897. Mr. W. J. Lewis Abbott.
1897. Mr. Joseph Lomas.
1898. Mr. William H. Shrubsole.
1898. Mr. Henry Woods.
1899. Mr. Frederick Chapman.
1899. Mr. John Ward.
1900. Miss Gertrude L. Elles.
1901. Dr. John William Evans.
1901. Mr. Alexander McHenry.
1902. Dr. Wheelton Hind.
1903. Mr. Sydney S. Buckman.
1903. Mr. George Edward Dibley.
1904. Dr. Charles Alfred Matley.
1904. Prof. Sidney Hugh Reynolds.
1905. Mr. E. A. Newell Arber.
1905. Mr. Walcot Gibson.
1906. Mr. William G. Fearnsides.
1906. Mr. Richard H. Solly.
1907. Mr. T. Crosbee Cantrill.
1907. Mr. Thomas Sheppard.
1908. Dr. Thomas Franklin Sibly.
1908. Mr. H. J. Osborne White.
1909. Mr. H. Brantwood Muff.
1909. Mr. Robert G. Carruthers.

AWARDS OF THE BIGSBY MEDAL,

FOUNDED BY THE LATE

DR. J. J. BIGSBY, F.R.S., F.G.S.

To be awarded biennially 'as an acknowledgment of eminent services in any department of Geology, irrespective of the receiver's country; but he must not be older than 45 years at his last birthday, thus probably not too old for further work, and not too young to have done much.'

1877. Prof. Othniel Charles Marsh.
1879. Prof. Edward Drinker Cope.
1881. Prof. Charles Barrois.
1883. Dr. Henry Hicks.
1885. Prof. Alphonse Renard.
1887. Prof. Charles Lapworth.
1889. Dr. J. J. Harris Teall.
1891. Dr. George Mercer Dawson.
1893. Prof. William Johnson Sollas.
1895. Dr. Charles D. Walcott.
1897. Mr. Clement Reid.
1899. Prof. T. W. E. David.
1901. Mr. George W. Lamplugh.
1903. Dr. Henry M. Ami.
1905. Prof. John Walter Gregory.
1907. Dr. Arthur W. Rogers.
1909. Dr. John Smith Flett.

AWARDS OF THE PRESTWICH MEDAL,

ESTABLISHED UNDER THE WILL OF THE LATE

SIR JOSEPH PRESTWICH, F.R.S., F.G.S.

'To apply the accumulated annual proceeds . . . at the end of every three years, in providing a Gold Medal of the value of Twenty Pounds, which, with the remainder of the proceeds, is to be awarded . . . to the person or persons, either male or female, and either resident in England or abroad, who shall have done well for the advancement of the science of Geology; or, from time to time to accumulate the annual proceeds for a period not exceeding six years, and apply the said accumulated annual proceeds to some object of special research bearing on Stratigraphical or Physical Geology, to be carried out by one single individual or by a Committee; or, failing these objects, to accumulate the annual proceeds for either three or six years, and devote such proceeds to such special purposes as may be decided.'

1903. John Lubbock, Baron Avebury.
1906. Mr. William Whitaker.
1909. Lady Evans.

AWARDS OF THE PROCEEDS OF THE BARLOW-JAMESON FUND,

ESTABLISHED UNDER THE WILL OF THE LATE

DR. H. C. BARLOW, F.G.S.

'The perpetual interest to be applied every two or three years, as may be approved by the Council, to or for the advancement of Geological Science.'

1879. Purchase of Microscope.
1881. Purchase of Microscope-Lamps.
1882. Baron C. von Ettingshausen.
1884. Dr. James Croll.
1884. Prof. Leo Lesquereux.
1886. Dr. H. J. Johnston-Lavis.
1888. Museum.
1890. Mr. W. Jerome Harrison.
1892. Prof. Charles Mayer-Eymar.
1893. Purchase of Scientific Instruments for Capt. F. E. Younghusband.
1894. Dr. Charles Davison.
1896. Mr. Joseph Wright.
1896. Mr. John Storrie.
1898. Mr. Edward Greenly.
1900. Mr. George C. Crick.
1900. Dr. Theodore T. Groom.
1902. Mr. William M. Hutchings.
1904. Mr. Hugh J. Ll. Beadnell.
1906. Mr. Henry C. Beasley.
1908. Contribution to the Fund for securing the Preservation of the Sarsen-Stones on Marlborough Downs, known as 'The Grey Wethers.'

AWARDS OF THE PROCEEDS

OF THE

'DANIEL PIDGEON FUND,'

FOUNDED BY MRS. PIDGEON, IN ACCORDANCE WITH THE WILL OF THE LATE

DANIEL PIDGEON, F.G.S.

'An annual grant derivable from the interest on the Fund, to be used at the discretion of the Council, in whatever way may in their opinion best promote Geological Original Research, their Grantees being in all cases not more than twenty-eight years of age.'

1903. Prof. Ernest Willington Skeats.
1904. Mr. Linsdall Richardson.
1905. Mr. Thomas Vipond Barker.
1906. Miss Helen Drew.
1907. Miss Ida L. Slater.
1908. Mr. James Archibald Douglas.
1909. Mr. Alexander Moncrieff Finlayson.

Estimates for

INCOME EXPECTED.

	£	s.	d.	£	s.	d.
Compositions				140	0	0
Due for Arrears of Admission-Fees	94	10	0			
Admission-Fees, 1909	201	12	0			
				296	2	0
Arrears of Annual Contributions	140	0	0			
Annual Contributions, 1909, from Resident and Non-Resident Fellows	1860	0	0			
Annual Contributions in advance	60	0	0			
				2060	0	0
Sale of the Quarterly Journal, including Longmans' Account				160	0	0
Sale of the 'History of the Geological Society'				20	0	0
Sale of the Centenary Record				10	0	0
Sale of Transactions, General Index, Library-Catalogue, Museum-Catalogue, Hutton's 'Theory of the Earth' vol. iii, Hochstetter's 'New Zealand,' and List of Fellows				6	0	0
Miscellaneous Receipts				10	0	0
Interest on Deposit-Account				10	0	0
Dividends on £2500 India 3 per cent. Stock	75	0	0			
Dividends on £300 London, Brighton, & South Coast Railway 5 per cent. Consolidated Preference Stock	15	0	0			
Dividends on £2250 London & North-Western Railway 4 per cent. Preference Stock	90	0	0			
Dividends on £2800 London & South-Western Railway 4 per cent. Preference Stock	112	0	0			
Dividends on £2072 Midland Railway 2½ per cent. Perpetual Preference Stock	51	16	0			
Dividends on £267 6*s.* 7*d.* Natal 3 per cent. Stock	8	0	0			
				351	16	0
				3063	18	0
Estimated excess of Expenditure over Income				77	10	0
				£3141	8	0

the Year 1909.

EXPENDITURE ESTIMATED.

	£ s. d.	£ s. d.
House-Expenditure:		
Taxes	15 0	
Fire-Insurance	15 0 0	
Electric Lighting and Maintenance	55 0 0	
Gas	25 0 0	
Fuel	40 0 0	
Furniture and Repairs	35 0 0	
*House-Repairs and Maintenance	190 0 0	
Annual Cleaning	15 0 0	
Tea at Meetings	20 0 0	
Washing and Sundry Expenses	40 0 0	
		435 15 0
Salaries and Wages, etc.:		
Assistant-Secretary	350 0 0	
,, half Premium Life-Insurance	10 15 0	
Assistant-Librarian	150 0 0	
Assistant-Clerk	150 0 0	
Junior Assistant	30 10 0	
House-Porter and Upper Housemaid	95 0 0	
Under Housemaid	48 18 0	
Charwoman and Occasional Assistance	10 0 0	
Accountants' Fee	10 10 0	
		855 13 0
Office-Expenditure:		
Stationery	35 0 0	
Miscellaneous Printing, etc.	50 0 0	
Postages and Sundry Expenses	85 0 0	
		170 0 0
Library (Books and Binding)		250 0 0
Library-Catalogue:		
Cards	15 0 0	
Compilation	50 0 0	
		65 0 0
Publications:		
Quarterly Journal, including Commission on Sale, and Centenary Record	1000 0 0	
Postage on Journal, Addressing, etc.	90 0 0	
Record of Geological Literature	130 0 0	
List of Fellows	35 0 0	
Abstracts, including Postage	110 0 0	
		1365 0 0
		£3141 8 0

* Including £170 for a new Boiler, in connexion with the heating apparatus.

HORACE W. MONCKTON, *Treasurer.*

February 5th, 1909.

Income and Expenditure during the

RECEIPTS.

	£	s.	d.	£	s.	d.
To Balance in the hands of the Bankers at January 1st, 1908	155	4	4			
,, Balance in the hands of the Clerk at January 1st, 1908	13	13	1			
				168	17	5
,, Compositions				105	0	0
,, Admission-Fees:						
Arrears	94	10	0			
Current	226	16	0			
				321	6	0
,, Arrears of Annual Contributions	157	10	0			
,, Annual Contributions for 1908:—						
Resident Fellows	1866	16	0			
Non-Resident Fellows	4	14	6			
,, Annual Contributions in advance	79	16	0			
				2108	16	6
,, Publications:						
Sale of Quarterly Journal*:						
,, Vols. i to lxiii	116	1	6			
,, Vol. lxiv	44	12	7			
				160	14	1
,, 'History of the Geological Society'.	....			23	9	3
,, General Index (Quarterly Journal).	1	1	5			
,, Abstracts			6			
,, Record of Geological Literature ...	2	14	10			
,, List of Fellows		7	0			
,, Hutton's 'Theory of the Earth,' vol. iii		2	6			
,, Hochstetter's 'New Zealand'		6	0			
,, Museum-Catalogue		2	9			
				4	15	0
,, Miscellaneous Receipts				10	1	0
,, Repayment of Income-Tax (1 year)				17	11	9
,, Interest on Deposit-Account				5	17	4
,, Dividends (less Income-Tax):—						
£2500 India 3 per cent. Stock	71	5	0			
£300 London, Brighton, & South Coast Railway 5 per cent. Consolidated Preference Stock	14	5	0			
£2250 London & North-Western Railway 4 per cent. Preference Stock	85	10	0			
£2800 London & South-Western Railway 4 per cent. Preference Stock	106	8	0			
£2072 Midland Railway $2\frac{1}{2}$ per cent. Perpetual Preference Stock	49	4	2			
£267 6*s.* 7*d.* Natal 3 per cent. Stock	7	12	4			
				334	4	6
				£3260	12	10

* A further sum is due from Messrs. Longmans & Co. for Journal-Sales £58 4 4

Year ended December 31st, 1908.

PAYMENTS.

	£	s.	d.	£	s.	d.
By House-Expenditure:						
Taxes		15	0			
Fire and other Insurance	16	8	8			
Electric Lighting and Maintenance	53	0	7			
Gas	22	14	10			
Fuel	41	9	4			
Furniture and Repairs	37	1	3			
House-Repairs and Maintenance	8	3	6			
Annual Cleaning	16	15	1			
Tea at Meetings	21	3	8			
Washing and Sundry Expenses	40	19	7			
				258	11	6
,, Salaries and Wages:						
Assistant-Secretary	350	0	0			
,, half Premium Life-Insurance	10	15	0			
Assistant-Librarian	150	0	0			
Assistant-Clerk	150	0	0			
Junior Assistant	57	19	0			
House-Porter and Upper Housemaid	94	5	3			
Under Housemaid	44	1	0			
Charwoman and Occasional Assistance	16	7	0			
Accountants' Fee	10	10	0			
				883	17	3
,, Office-Expenditure:						
Stationery	23	10	1			
Miscellaneous Printing	53	14	10			
Postages and Sundry Expenses	76	2	9			
				153	7	8
,, Library (Books and Binding)				218	9	10
,, Library-Catalogue:						
Cards	17	7	3			
Compilation	50	0	0			
				67	7	3
,, Publications:						
Quarterly Journal, Vols. i–lxiii, Commission on Sale thereof	10	8	8			
Quarterly Journal, Vol. lxiv, Commission on Sale thereof	2	17	9			
Paper, Printing, and Illustrations	835	19	9			
Postage on Journal, Addressing, etc.	109	14	3			
Record of Geological Literature	150	15	9			
List of Fellows	35	12	6			
Abstracts, including Postage	112	19	7			
				1258	8	3
'History of the Geological Society'	....			125	17	7
Centenary Record	....			96	13	4
,, Balance in the hands of the Bankers at December 31st, 1908	180	8	0			
,, Balance in the hands of the Clerk at December 31st, 1908	17	12	2			
				198	0	2
				£3260	12	10

We have compared this Statement with the Books and Accounts presented to us, and find them to agree.

A. STRAHAN,
C. GILBERT CULLIS, } *Auditors.*

HORACE W. MONCKTON, *Treasurer.*

February 5th, 1909.

Statement of Trust-Funds: December 31st, 1908.

'Wollaston Donation Fund.' Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1908	32	3	10	By Cost of Medal	10	10	0
,, Dividends (less Income-Tax) on the Fund invested in £1073 Hampshire County 3 per cent. Stock	30	11	6	,, Award from the Balance of the Fund	21	13	10
,, Repayment of Income-Tax (1 year)	1	12	4	,, Balance at the Bankers' at December 31st, 1908	32	3	10
	£64	7	8		£64	7	8

'Murchison Geological Fund.' Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1908	16	18	2	By Award to the Medallist	10	10	0
,, Dividends (less Income-Tax) on the Fund invested in £1334 London & North-Western Railway 3 per cent. Debenture Stock	38	0	4	,, Award from the Balance of the Fund	25	8	4
,, Repayment of Income-Tax (1 year)	2	0	0	,, Balance at the Bankers' at December 31st, 1908	21	0	2
	£56	18	6		£56	18	6

'Lyell Geological Fund.' Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1908	48	10	10	By Award to the Medallist	25	0	0
,, Dividends (less Income-Tax) on the Fund invested in £2010 1*s.* 0*d.* Metropolitan $3\frac{1}{2}$ per cent. Stock	66	16	8	,, First Award from the Balance of the Fund	20	2	6
,, Repayment of Income-Tax (1 year)	3	10	4	,, Second Award from the Balance of the Fund	20	2	6
				,, Balance at the Bankers' at December 31st, 1908	53	12	10
	£118	17	10		£118	17	10

'Barlow-Jameson Fund.' Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1908	13	5	11	By Balance at the Bankers' at December 31st, 1908	27	6	9
,, Dividends (less Income-Tax) on the Fund invested in £468 Great Northern Railway 3 per cent. Debenture-Stock	13	6	10				
,, Repayment of Income-Tax (1 year)		14	0				
	£27	6	9		£27	6	9

'Bigsby Fund.' Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1908	3	6	2	By Balance at the Bankers' at December 31st, 1908	9	12	2
,, Dividends (less Income-Tax) on the Fund invested in £210 Cardiff 3 per cent. Stock	5	19	8				
Repayment of Income-Tax (1 year)		6	4				
	£9	12	2		£9	12	2

'Geological Relief Fund.' Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1908	33	6	11	By Grants	6	6	0
,, Dividends (less Income-Tax) on the Fund invested in £139 3*s.* 7*d.* India 3 per cent. Stock	3	19	4	,, Balance at the Bankers' at December 31st, 1908	31	4	5
,, Repayment of Income-Tax (1 year)		4	2				
	£37	10	5		£37	10	5

'Prestwich Trust Fund.' Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1908	22	9	9	By Balance at the Bankers' at December 31st, 1908	43	9	6
,, Dividends (less Income-Tax) on the Fund invested in £700 India 3 per cent. Stock	19	19	0				
,, Repayment of Income-Tax (1 year)	1	0	9				
	£43	9	6		£43	9	6

'Daniel Pidgeon Fund.' Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1908	16	0	11	By Award	30	11	4
,, Dividends (less Income-Tax) on the Fund invested in £1019 1*s.* 2*d.* Bristol Corporation 3 per cent. Stock	29	0	10	,, Balance at the Bankers' at December 31st, 1908	16	0	11
,, Repayment of Income-Tax (1 year)	1	10	6				
	£46	12	3		£46	12	3

We have compared this Statement with the Books and Accounts presented to us, and find them to agree.

HORACE W. MONCKTON, *Treasurer.*

February 5th, 1909.

A. STRAHAN,
C. GILBERT CULLIS, } *Auditors.*

Statement relating to the Society's Property :

December 31st, 1908.

	£	s.	d.	£	s.	d.
Balance in the Bankers' hands, December 31st, 1908 :						
On Current Account	180	8	0			
Balance in the Clerk's hands, December 31st, 1908	17	12	2			
				198	0	2
Due from Messrs. Longmans & Co., on account of Quarterly Journal, Vol. LXIV, etc.	......			58	4	4
Arrears of Admission-Fees	94	10	0			
Arrears of Annual Contributions	201	16	0			
				296	6	0
				£552	10	6
Funded Property, at cost price :—						
£2500 India 3 per cent. Stock	2623	19	0			
£300 London, Brighton, & South Coast Railway 5 per cent. Consolidated Preference Stock	502	15	3			
£2250 London & North-Western Railway 4 per cent. Preference Stock	2898	10	6			
£2800 London & South-Western Railway 4 per cent. Preference Stock	3607	7	6			
£2072 Midland Railway $2\frac{1}{2}$ per cent. Perpetual Preference Stock	1850	19	6			
£267 6*s.* 7*d.* Natal 3 per cent. Stock	250	0	0			
				11,733	11	9

[*N.B.—The above amount does not include the value of the Collections, Library, Furniture, and Stock of unsold Publications. The value of the Funded Property of the Society at the prices ruling at the close of business on December 31st, 1908, amounted to £9842 4s. 7d.*]

HORACE W. MONCKTON, *Treasurer.*

February 5th, 1909.

Award of the Wollaston Medal.

In presenting the Wollaston Medal to Mr. Horace Bolingbroke Woodward, F.R.S., the President addressed him as follows :—

Mr. Woodward,—

The Wollaston Medal is awarded to you in recognition of researches conducive to the interests of the Society in particular and to the science of Geology in general, especially in relation to the Jurassic rocks of Britain and the 'History of the Geological Society.'

No one possesses a more encyclopædic knowledge of the Geology of England and Wales than yourself, and your well-known book on this subject, distinguished by its clear and orderly presentation of a vast collection of facts, is indispensable to every English student of our science.

The Jurassic System, as developed in this country, has long occupied your attention, and you have given an admirable account of it in your three great volumes on 'The Jurassic Rocks of England & Wales'; a work which embodies your own personal observations, and fully and impartially records every fact of importance contributed by other investigators.

The invaluable 'History of the Society' which you prepared for our Centenary Celebration is a mine of information, and at the same time a continuous and consistent story well told. The heroic figures and the battles of long ago are brought vividly before our eyes; and the human side of our great predecessors is faithfully touched in with many a quaint saying, odd mannerism, and witty story. As we read, we are conscious of a deepening appreciation of the great and lovable nature of the men who helped to found and build up our science, and an increased pride in the Society which they have transmitted to our care.

Your retirement from the Geological Survey will doubtless be merely the introduction to a new sphere of activity; the good wishes of the Society will follow you there; and we hope that you will live long to enjoy the powers conferred upon you by your well-earned leisure.

Mr. Woodward replied in the following words :—

Mr. President,—

In receiving from your hands the Wollaston Medal I feel

intensely gratified that my work has been adjudged by the Council to be worthy of this great honour.

I cannot claim to be one who engaged in the 'Pursuit of Knowledge Under Difficulties,' as the Society in my early days, and the Geological Survey afterwards, directed my steps and made the pathways smooth. Thus, whether under command or away from official control, ambition was stirred to make as full acquaintance as possible with the Geology of this country. In almost every part of it we have the advantage of following in the footsteps of previous geological workers, and as progress could not be made without heed to the lessons which they have taught, it is natural that some of us should be led from the rocks into historical and biographical trackways. In these directions, from the field to the study, my tasks have conducted me; and, while I recognize that, as a recipient of this Award, I am highly privileged, I rejoice in the weight attached to researches which indicate how much we are indebted to those who have gone before us.

I thank you, Sir, for the very kind words with which you have accompanied this presentation.

Award of the Murchison Medal.

The President then presented the Murchison Medal to Prof. Grenville A. J. Cole, F.G.S., addressing him as follows:—

Professor Cole,—

In awarding you the Murchison Medal the Council wish to express their appreciation of the value of your contributions to Geology in general and especially to Petrology.

You have combined, in the happiest manner, work in the laboratory with observations in the field; in addition, your petrological studies have been so arranged as to lead naturally to comparative results; and by visiting allied areas you have caused each in turn to throw light upon the other. The tachylytes of Scotland thus led you to the variolitic masses of the Hautes Alpes, and Hungary was thus made the basis for the description of the rhyolites of Antrim.

Impressed by the modifications suffered by igneous magmas through the absorption of foreign material, you were led to important conclusions with regard to the granite of Slieve Gallion in

Londonderry; and in Tyrone and Donegal you found in the phenomena of igneous intrusion an explanation of the structure of gneisses which had been previously attributed to dynamometamorphic action.

Since 1905 you have been called to direct the work of the Geological Survey of Ireland, and have endeavoured to connect the study of soils with the underlying drift and older rocks.

Not the least merit of your work is the endeavour to present your results in a pure and simple literary style.

We have made many excursions together on Irish soil, and I have had frequent opportunities to observe, not without admiration, how keen is your interest, how untiring your enthusiasm, and how ample your enjoyment when brought face to face with the knotty problems of the field.

The memory of our association in the past adds to the pleasure with which I hand you the Murchison Medal.

Prof. Cole replied in the following words:—

Mr. President,—

I beg to thank you and the Council of the Geological Society for the generous and unexpected award made to me to-day. In your friendly references to my work, you have fully appreciated the aim of my petrological studies, although I fear that you have been unduly kind to the performance. The illustrious founder of the medal which I now receive laid stress, in common with his contemporaries, on the necessity for the comparison of geological phenomena in many lands besides our own. Travel, it was urged, was one of the first duties of a geologist, and this was never lost sight of in the training that I received from my own revered master, Prof. Judd. In my far smaller way, I have always endeavoured to realize that a rock-specimen is not a mineralogical curiosity, but a portion of this very vital globe on which our destinies are cast. It is an especial pleasure, Mr. President, for me to receive this encouragement from your hands, since the work so kindly recognized has been mainly done in Ireland. When, eighteen years ago, I entered that country as a stranger, you freely placed before me the results of your own enquiries, and year by year you stimulated me by your energy in research. May I venture also to think—you, Sir, have opened the way for me to say it—that the Geological Survey of Ireland, which has so kindly received me as a colleague, becomes again to-day associated with the historic name of Murchison?

Award of the Lyell Medal.

In presenting the Lyell Medal to Prof. Percy Fry Kendall, M.Sc., the President addressed him as follows:—

Professor Kendall,—

The Lyell Medal has been awarded to you by the Council as a mark of honorary distinction and as an expression on the part of the Council that you have deserved well of the Science, especially by your researches into the Glacial Geology of England.

The success which has attended your performance of the arduous duties connected with the Professorship of Geology in a young University has only been achieved by strenuous labour; that you have been able at the same time to accomplish so much in the field of research is a striking testimony to your indomitable energy.

Your delightful account of the Geology of Yorkshire, with its wealth of detail and breadth of view, is a model of its kind, and your report to the Royal Commission on the Concealed Coalfields of North-Eastern England is important, both from a theoretical and from a practical point of view; but to the Fellows of this Society you are probably better known by your long-continued and successful researches into Glacial phenomena, and especially by your brilliant account of the Glacial Lakes of Cleveland.

I sincerely trust that the future may have in store a larger share of time and opportunity for the exercise of your original powers.

Prof. Kendall replied in the following words:—

Mr. President,—

I thank the Council most heartily for the honour which it has done me in the award of this valued distinction, and you, Sir, for the generous terms in which you have conveyed it.

My lot as a geologist has been cast in very pleasant places. I have been trebly fortunate in my teachers, for, while my studies in early manhood were directed by such distinguished exponents of our science as my friend and master, Prof. Judd, and his lieutenant, Prof. Grenville Cole, I owe not a little to the fact—until this moment unknown to you—that, at a still earlier period in my career, I had the advantage of attending a course of lectures in the City of London delivered by you.

This inspiration fanned to a glow the fire of enthusiasm for Geology that is among my earliest recollections, and will, I doubt not, last to the end of my life.

I have found in Yorkshire a wide and varied field, replete with problems of the highest scientific interest and economic importance, which press so insistently for solution that the temptation has been great to pass on from one half-solution to another. It is most gratifying to find that my small measure of achievement has commended itself to the Council of the Geological Society.

I must not forget an acknowledgment of the debt that I owe to the many enthusiastic brother-geologists in the county of my adoption, who have helped and encouraged me in the field, and by frank and friendly criticism have saved me from not a few downright blunders.

Award of the Bigsby Medal.

The President then presented the Bigsby Medal to Dr. John Smith Flett, M.A., addressing him as follows:—

Dr. Flett,—

In a series of masterly memoirs published during the past thirteen years, you have greatly extended our knowledge of the geology and petrography of Great Britain, particularly of Scotland and Cornwall.

The responsible post of Petrographer to the Geological Survey has brought you many opportunities, of which you have made such excellent use that you have come to be generally recognized as a worthy successor to Dr. Teall, and than this I know of no higher praise.

You have not confined your studies to these islands, but have given us descriptions of the rocks of remote parts of the world. At the call of duty and in the pursuit of Science you visited, in company with Dr. Tempest Anderson, St. Vincent and Martinique, and gathered your facts amidst the explosions of Mount Pelé. From my own experience of other active, if less ferocious, volcanoes, I know something of the demands which this makes on the coolness and courage of the observer. It is, therefore, with the sympathy of a comrade in arms that I hand you this Medal in the name of the Council.

Dr. Flett replied in the following words:—

Mr. President,—

The honour which the Society has done me by awarding to me the Bigsby Medal is one of which I am deeply sensible. I can assure you, Sir, that it will be my endeavour to see that the stimulus that it gives to earnest scientific work, the injunction 'not to rust unburnished, but to shine in use,' will not pass unregarded. In the study of British rocks, principally the igneous and metamorphic, I have had exceptional advantages; for I have received the kindest assistance from my colleagues on the Geological Survey, and especially from Dr. Teall, who also by his example has placed before me the highest ideals of thoroughness and accuracy in investigation. The labour spent in research is in the best sense its own reward, but the pleasure which I have derived from it has been greatly increased by the approbation which you have expressed this afternoon in handing to me this Medal.

Award of the Prestwich Medal.

In presenting the Prestwich Medal to Lady Evans, the President addressed her as follows:—

Lady Evans,—

The Council has awarded to you the Prestwich Medal *in memoriam* of Sir John Evans.

It is now fifty years since Sir John Evans, in company with his life-long friend Sir Joseph Prestwich, visited the scene of Boucher de Perthes's famous discoveries at Abbeville. The results of that visit in its effect upon the whole range of human thought would be difficult to estimate: one of them is apparent in the increasing growth of that new branch of Science—the Anthropology of the Pleistocene Epoch—which Sir John Evans did so much to create.

This award commemorates in some sense the joint labours of the two friends; that it was not made earlier is due to Sir John Evans's long-continued and self-denying services on the Council.

We esteem ourselves fortunate that you, Lady Evans, who shared his interests, and are yourself an antiquary, are able to be present on this occasion, and in handing you this Medal, I desire to express, on the part of the Society, our deep appreciation of the unceasing devotion and affectionate solicitude with which

its interests were watched over by our lost leader, whose memory we shall long preserve.

On behalf of Lady Evans, Mr. Lewis Evans replied in the following words :—

Mr. President.—

Speaking on behalf of Lady Evans and my late father's family, I have to express our great appreciation of the honour which the Society has paid to his memory in awarding to her the Prestwich Medal; we also recognize the special fitness of the award because of the long, unbroken, and most intimate friendship between Sir Joseph Prestwich and my father; and because, on account of his knowledge of medallic art, my father was chiefly responsible for the design of this medal.

To you, Sir, I wish to tender our special thanks for your kind and sympathetic words on the occasion of this presentation, terminating in so graceful a manner the fifty-year-long connexion between my father and your illustrious Society.

Award of the Wollaston Donation Fund.

The President then handed the Balance of the Proceeds of the Wollaston Donation Fund to Mr. Arthur John Charles Molyneux, F.G.S., addressing him as follows :—

Mr. Molyneux,—

Thanks to the enterprise of scientific explorers, the Continent of the Sphinx is slowly yielding up its mysteries.

One of these explorers we are glad to welcome in your person on this occasion. We owe to your exertions important contributions to our knowledge of the geology of Southern Rhodesia and Bechuanaland: all of these are distinguished by carefulness of description and caution in inference.

You were the first to give a scientific account of the Victoria Falls, and to explain their origin. When the British Association visited the Falls in 1905, your work was very searchingly criticized; along with my fellow-geologists, I had the satisfaction of recognizing its faithfulness to fact as well as its theoretical adequacy.

We are all glad to find that the climate of Africa has treated you leniently, and we hope that when you return you will be able to throw further light on that still mysterious continent.

Award of the Murchison Geological Fund.

In presenting the Balance of the Proceeds of the Murchison Geological Fund to Mr. James Vincent Elsden, B.Sc., the President addressed him in the following words :—

Mr. Elsden,—

The Balance of the Murchison Geological Fund has been awarded you by the Council, on account of your work among the Igneous Rocks of Wales, and to encourage you in further research.

Since your earliest work in 1883, you have continued to make welcome additions to our knowledge, particularly in the application of geology to the arts, and you have enriched the literature of British petrography by excellent papers on the igneous rocks of the Lleyn district, Llyn Padarn, and Pembrokeshire. These contributions are distinguished by their philosophic treatment of accurately described data, in the light of the most recent advances in chemistry and physics.

We wish you health and opportunity to continue your important work of research.

Awards from the Lyell Geological Fund.

The President then presented one moiety of the Balance of the Proceeds of the Lyell Geological Fund to Mr. Herbert Brantwood Muff, B.A., addressing him as follows :—

Mr. Muff,—

A moiety of the Balance of the Proceeds of the Lyell Geological Fund has been awarded to you, in recognition of your researches among the Pleistocene deposits and the ancient rocks of Scotland and Ireland.

As a result of your researches on Glacial deposits in this country, you have indicated a lower limit for the ancient snow-line, at least in the vicinity of Bradford, where it did not descend beyond 1500 feet above the present sea-level; and in company with Mr. W. B. Wright you have established a pre-Glacial limit to the sea along the southern coast of Ireland, which corresponds in a remarkable manner with that now existing.

You have also carried your hammer into the tropics, and published a valuable report on the Geology of British East Africa.

Recently, in conjunction with Mr. Carruthers, you have investigated the West of Ireland, where you have discovered a thick series of Arenig rocks, and shown that the crystalline schists of Connemara were metamorphosed before the Arenig Epoch, and probably before the Cambrian Era.

You are now engaged in studying the perplexing problems of the Western Highlands of Scotland. May your labours be crowned with equal success!

In handing the other moiety of the Balance of the Proceeds of the Lyell Geological Fund, awarded to Mr. Robert George Carruthers, to Prof. E. J. Garwood, Sec.G.S., for transmission to the recipient, the President addressed him in the following words:—

Professor Garwood,—

The Council have assigned a moiety of the Balance of the Lyell Geological Fund to Mr. R. G. Carruthers, in recognition of his work on the Carboniferous Corals, and to stimulate him to further research.

The task of subdividing the Carboniferous Limestone into definite zones has engaged the energies of a brilliant band of investigators, and no one has contributed more fundamental data than Mr. Carruthers. The recognition of distinctive characters among forms apparently so indefinite as the corals is a difficult problem, taxing to the utmost the judgement, skill, and patience of the observer. It is one which he has undertaken, and so far with conspicuous success.

In asking you to transmit this Award to Mr. Carruthers, I would beg you to assure him of the cordial interest taken by the Council in the progress of his labours.

THE ANNIVERSARY ADDRESS OF THE PRESIDENT,

Prof. William Johnson Sollas, LL.D., Sc.D., F.R.S.

During the past year we have suffered heavily under the visitation of death. We mourn the loss of three past Presidents, three Foreign Members, and, besides other aged and distinguished friends and colleagues, we have especially to lament several of our younger Fellows cut off untimely in the fulness of their powers.

Henry Clifton Sorby (1826–1908).—As if by a kind of compensation for the supineness of those in high places, Science has always been distinguished in this country, more than others, by the number and brilliance of its amateurs, and among these one of the most brilliant was Henry Clifton Sorby.

His family on the father's side had long given proof of unusual ability, his grandfather was Master Cutler of the Cutlers' Company, and an earlier ancestor, who died in 1628, was the first of the long line of Master Cutlers. If from his father he inherited his shrewd good sense and sound judgement, it was to his mother—Amelia Lambert—that he owed much of his intellectual strength and alertness.

He was born on May 10th, 1826, at Woodhouse, near Sheffield. From his earliest days his tendency was towards scientific studies, and this he tells us was strengthened by a book called 'Readings in Science,' which he received as a prize for arithmetic when attending the Sheffield Collegiate School.

On leaving school he received instruction from a private tutor, the Rev. Walter Michel, a mathematician, who had enjoyed the advantage of a medical training, and consequently possessed a good knowledge of chemistry and anatomy. He will be well known to some Fellows of the Society as the author of a work on Crystallography, which appeared in Orr's 'Circle of the Sciences.' The relations of pupil and tutor were evidently cordial: as Sorby expresses it, 'we worked together' not only at mathematics, but also at chemistry and anatomy. On the removal of his tutor, Sorby continued his studies alone, paying particular attention to optics. He also found time for practice in water-colour drawing and acquired considerable skill, as may be seen from the carefully finished studies of clouds, which he painted when investigating their forms on board his yacht the *Glimpse*.

Looking back towards the close of his life, Sorby regarded his early training with complete approval: he had found it 'of the greatest possible value' in all the investigations he had undertaken. It says much for his natural gifts that he was able to dispense with the discipline of examinations, and that the special qualities of exactitude and completeness which it fosters are none the less distinctive characteristics of all his work.

The happy possessor of a private fortune, Sorby was able to devote himself unreservedly to the work of discovery, which engaged all his energies from his first paper, written in his 20th year, to the last day of his life at the ripe age of 81.

The earliest essays of original genius are often surprisingly commonplace. Faraday's first contribution to science was the analysis of a piece of lime; Sorby's, a collection of analyses which he had made in order to determine the amount of sulphur and phosphorus present in various kinds of agricultural crops.

Very soon, however, he plumed his pinions to wider flights. Fundamental problems in geology, especially such as are connected with the deposition of sediments, early engaged his attention and continued to occupy his thoughts throughout his life: his latest as well as many of his earlier papers are devoted to this subject, and he expressed his surprise, which every thoughtful geologist must share, that it has not received more general investigation. But Sorby's first great achievement was the application of the microscope to the study of rocks. The process of preparing thin sections of hard bodies for examination under the microscope had been practised since the time of Nicol, who was, I believe, its inventor; Sorby learnt it from William Crawford Williamson of Manchester, and was fascinated by a method which opened a way into the unseen.

The first transparent slice of a rock was made by him in 1849, and the first petrographical study based on thin slices was an account of the minute structure of the calcareous grit of Scarborough, read before this Society in 1850 and published in our Journal in 1851. Almost all the methods commonly employed at the present day in the microscopical study of rocks, including the application of polarized light, were already familiar to Sorby at this early date.

The powers of the new method were next to be felt in a still more difficult field of enquiry. Daniel Sharpe had shown by an excellent piece of inductive reasoning that slaty cleavage was a

consequence of mechanical pressure. Sorby made several deductions from this conclusion, and then proceeded to verify them: on the one hand by observations on the minute structure of slate as revealed in thin slices, and on the other by experiment, as when he showed that certain substances, such as pipeclay mixed with scales of iron-oxide, actually acquire the property of cleavage on being subjected to pressure, and further, that a definite relation exists between the direction in which the pressure acts and that in which the cleavage-planes are developed. They are perpendicular in the experiment, as they are required to be by theory founded on observations in the field. Sorby's account of his work was read before our Society; and it will be a source of gratification to those whose papers may not always have received the sympathy which they may have thought they had a right to expect, to know that it proved too novel for some of the mathematical dogmatists of the time, and was printed in consequence in the Edinburgh New Philosophical Journal. Sorby returned to the subject on more than one occasion, producing much additional evidence, the best known being the contorted band of quartzite in the slates of Ilfracombe, which Lyell afterwards figured in his 'Elements.'

From cleavage it was a natural transition to foliation, and as a result of much laborious work, Sorby was able to show that both parties in a controversy on this subject were in the right, for in some cases the foliation was found to follow the bedding and in others the cleavage-planes.

A much vaster realm of the obscure now began to open before our explorer, and it was not long before he had penetrated into the deeper mysteries of the igneous rocks. His first great paper on this subject—'Some Peculiarities in the Inner Structure of Crystals, applied to the Determination of the Aqueous & Igneous origin of Minerals & Rocks'—was read before the Society on December 16th, 1857. The most flattering testimony to its merits was contributed by the chairman, who remarked 'that although he had been a member of the Society since its foundation, he did not remember, during the whole of that time, any communication which drew so largely on their credulity.' The genial John Phillips, on the other hand, who was present on that occasion and had followed Sorby's earlier work on cleavage with keen appreciation, was among the first to recognize the value and promise of this pregnant investigation.

It is interesting in this connexion to recall how one of our most

honoured Foreign Members, a man known and beloved by all—Ferdinand Zirkel—was led to build the superstructure of modern Petrography on the foundations which Sorby had laid. It was in 1862 that Sorby, when travelling with his mother up the Rhine, made the acquaintance of Zirkel, then a student in the mining department of Prussia. They visited together the Eifel, the Siebengebirge, and the lake of Laach, and during their excursions they eagerly discussed the nature of the volcanic rocks, their mineral composition, and their intimate structure as revealed by the microscope. Sorby described with enthusiasm the wonderful results of his own studies, and after the day's work the conversation was continued into the night. Finally, on returning to Bonn, Zirkel was shown under the microscope some of the slides which Sorby had prepared with his own hands. To Zirkel it was a revelation, and from that time onwards he devoted himself enthusiastically to the development of the new Petrography. Thus was the torch handed on!

It would be a mistake to suppose that Sorby contented himself with mere pioneering expeditions into unknown fields. His work so far as it went was thorough, and his theoretical views were always in advance of his work. Had it been otherwise, it would not have proved so fruitful. Scarcely any of the ideas which are now agitating the minds of petrologists would have proved altogether strange to Sorby. Consider his views on the order of consolidation in igneous rocks: how modern is this! The magma contains minerals in solution, as water contains salts; on cooling they are deposited, and crystallize out *at a temperature below that of their fusion-point when fused alone!* As an analogy he cites the case of aqueous solutions, when very infusible salts crystallize out after the very fusible water, and may be obtained growing upon crystals of ice. This view, published in 1858, stands quite apart from another, perhaps better known, in which he attributes a certain amount of water to the composition of the magma itself, as in the case of granite: a conclusion which seems to follow from his study of quartz-veins.

The seductive problem of allotropy, in which Nature seems to be on the verge of revealing the secrets of crystalline structure, could not fail to appeal to the mind of Sorby; and the more speculative side of his genius, still allied however with experiment, appears in a series of papers on the tetramorphism of carbon. These contain some anticipations of views expressed by Mr. Barlow and myself.

Later the same phenomenon of allotropy is turned to a more useful account, as in the study of the history of various limestones, which culminated in the Address delivered at our Anniversary Meeting in 1879, when the important part played by aragonite was pointed out.

The study of pseudomorphism was also a favourite study, and led to an explanation of the Cleveland Hill ironstone as a replacement-product of limestone. It is characteristic of all Sorby's work that observation, whenever possible, was accompanied by experiment, and in this case experiments were started which showed that, given time enough—these lasted 37 years—carbonate of iron in solution will replace carbonate of lime at ordinary temperatures.

Reflection on some of the changes which have affected rock-masses known to have been subject to great pressure led to an enquiry into the correlation of mechanical and chemical forces, and this formed the subject of the Bakerian Lecture which was delivered before the Royal Society in 1863.

The unknown liquid, distinguished by its extraordinarily high coefficient of expansion, which Brewster had discovered in crystals of tourmaline, was identified by Sorby with carbon-dioxide. Had he only pushed his enquiries into this matter a little further, he would in all probability have anticipated Andrews in some of his discoveries with regard to the critical point.

Many facts of interest were elicited by his examination of loose sands; such, for instance, as the characteristic rounding of the quartz grains in deserts, and the formation of crystalline sandstones by a subsequent deposit of quartz, which renewed the growth of the original grains.

The microscopic investigation of igneous rocks found its natural continuation in a similar investigation of meteorites. The results, which are of great interest, may be given almost in his own words:—

'A most careful study of their microscopical structure leads me,' he wrote, 'to conclude that their constituents originally existed at such a high temperature that they must have been in a state of vapour. . . . On cooling, this vapour condensed into a sort of cometary cloud, formed of small crystals and minute drops of melted stony matter, which afterwards became more or less . . . crystalline. This cloud was in a state of great commotion, and the particles moving with great velocity were often broken by collision. After collecting together to form large masses, heat, generated by mutual impact or . . [otherwise] . . gave rise to a variable amount of metamorphism. In some few cases, when the whole mass became fused, all evidence of a previous history was obliterated; and on solidification a structure was produced, quite similar to that of terrestrial volcanic rocks. Such metamorphosed or fused masses wer

sometimes more or less completely broken up by violent collision, and the fragments again collected together and solidified. Whilst these changes were taking place, various metallic compounds of iron were so introduced as to indicate that they still existed in space in the state of vapour, and condensed amongst the previously formed particles of the meteorites. At all events, the relative amount of the metallic constituents appears to have increased with the lapse of time, and they often crystallised under conditions differing entirely from those which occurred when mixed metallic and stony materials were metamorphosed, or solidified from . . . fusion. . . .'

It was in order to explain the origin of meteoric iron that Sorby commenced that remarkable series of investigations into artificial irons, which has since developed into a new science—micro-metallography—now proving of such immense importance in its application to the arts. His first work on this subject was commenced in 1863, and the results were published in the following year. Twenty-two years elapsed before they attracted any attention; but, after publishing a paper on the application of very high powers to the study of the microscopic structure of steel, which appeared in the Journal of the Iron & Steel Institute for 1866, Sorby was requested by that Institute to continue his work, and Dr. Percy and Sir Henry Bessemer were appointed to act with him in deciding as to the best way of illustrating a complete paper on the subject. Sorby proved that the different kinds of iron and steel are varying mixtures of well-defined substances, and that their structure is in many respects analogous to that of igneous rocks. To one of these constituents the name of Sorbite has been given in his honour.[1]

It is pleasing to reflect that by these researches the descendant of a long line of workers in iron and steel was able to continue the traditions of his family on another plane; and again, that micro-metallography is now one of the most important means of research employed by the Professor of Metallurgy who holds his chair in that University which Sorby did so much to create. What important practical results may follow from the scientific training given in this University may be gathered from Mr. Haldane's address to the British Science Guild on January 18th, 1908, when he spoke of his visit to one of the great Sheffield foundries, where he found among the employees men who had been students in the University, and was informed by one of the heads of the business that Sheffield was all but unique in the training given in this way to its young

[1] Since this is the name of a crystalline principle found in the berries of the mountain-ash, it would be better to alter the spelling to Sorbyite.

men; the result was that his firm commanded markets of which they could not have dreamed some time ago.

Sorby states that it was the study of meteorites which led him to invent the spectrum-microscope, with an arrangement for obtaining direct vision. He applied this instrument to the study of organic colouring-matter, and published altogether some forty papers on the subject. It is probable, however, that a brilliant future still awaits this instrument, and that it will find an important application in petrographical investigation.

After the death of his mother, to whom he was deeply attached, Sorby lived on board his yacht—a veritable floating laboratory—for five months of each year from 1879 to 1903, when he met with an accident which confined him to his bed. He endured this restraint upon his liberty with the utmost cheerfulness, and continued his work no less ardently than before. His last paper, written under these adverse circumstances, was read before the Society on January 8th, 1908, and it betrays no decay of power. It is distinguished by acuteness of observation, ingenuity in experiment, soundness of judgement, fertility in suggestion, and, not least, by a constant endeavour to obtain numerical results—the same characteristics, indeed, as are to be found in all his work.

Dr. Sorby was elected a Fellow of this Society in 1850, and in 1869 he received the Wollaston Medal. He held the office of President in 1878 and 1879, and delivered two memorable addresses which are important contributions to original research. His address when President of the Geological Section of the British Association was also a piece of original work. He was elected a Fellow of the Royal Society in 1857, and delivered the Bakerian Lecture in 1863. In 1874 he received a Royal Medal for his researches in slaty cleavage and on the minute structure of minerals and rocks, for the construction of a micro-spectroscope, and for his researches on colouring-matters. The University of Cambridge conferred upon him the honorary degree of LL.D. in 1879. From the Dutch Society of Sciences of Haarlem he received the first large Boerhaave Medal, which is only awarded once in twenty years. He was President of the Council and Chairman of the Executive Committee of Firth College (which he did much to found), from 1883 till its absorption into the University of Sheffield in 1897. He was the first President of the Yorkshire Naturalists' Union; but it was in the rooms of the Literary & Philosophical Society of his native city that he found himself most at home. From the commencement of his

career, when he communicated to that Society a paper on 'The Formation of Valleys, & on the Modern & Ancient River-Action in the Neighbourhood of Sheffield,' in 1847, down to 1900, few years were allowed to pass without some contribution to its Proceedings. The Society, in celebrating the jubilee of his connexion with it, presented him with his portrait.

During our celebration of the Centenary of the Geological Society a congratulatory message was sent by the petrographers who were assembled on that occasion, addressed to Sorby as 'The Father of Microscopical Petrography.' The pleasure this gave him was deep as it was touching.

Sorby was beloved by all who knew him. The visitor was sure to carry away a sunny memory of his genial and cheerful presence. His fellow-townsmen were proud of him, those who were his associates in the religious and intellectual life of the city almost idolized him. He was the most unaffected and warm-hearted of men, keeping to the end the freshness and fun of a boy. Though kind, his kindness was tempered with shrewdness. His cheerfulness was unlimited: after breaking his leg in bed, he congratulated himself that the accident had occurred under such comfortable circumstances. He had a fund of anecdote, and was never unwilling to talk about his own work to an interested listener. He was genuinely pleased that the work was his, openly glad to hear it well spoken of, and yet without a trace of vanity. 'In all my acquaintance with him,' remarks his friend Prof. W. M. Hicks, 'I never heard him utter an unkind criticism of any one.'

Sorby, like Darwin, was an amateur; professors he helped to make, and part of his fortune was bequeathed to the University of Sheffield for the endowment of a chair of Geology.

In this great enquiring spirit our Science has lost one of her most devoted and most distinguished sons.

Note.—For additional information, reference may be made to an article signed F. S. in the 'Naturalist' for 1906, where also a list of Sorby's papers, revised by himself, will be found; to an obituary notice by Sir Archibald Geikie in the Proceedings of the Royal Society, 1908, vol. lxxx; to articles in the 'Geological Magazine' 1908, vol. v, and in the 'Mineralogical Magazine' 1908, vol. xv, by Prof. Judd; 'Fifty Years of Scientific Research' in the Proc. Sheffield Lit. & Phil. Soc. 1897, by Sorby himself; and an article by

Prof. W. M. Hicks in 'Floreamus: the Chronicle of the University of Sheffield' for 1908, vol. iii.

Sir John Evans, K.C.B. (1823–1908).—John Evans was born on November 17th, 1823, at Britwell Court, Burnham (Buckinghamshire). His father, the Rev. Dr. Arthur Evans, was headmaster of the Grammar School at Market Bosworth (Leicestershire), and the author of numerous poems, theological essays, and a book on 'Leicestershire Words, Phrases, & Proverbs.' His grandfather, Lewis Evans, F.R.S., was the first mathematical master in the Royal Military Academy, Woolwich, and an amateur astronomer. On his mother's side he was descended from an Huguenot branch of an old French family. The gifts, plentifully bestowed upon him by heredity, lost nothing by a sedulous cultivation, and were applied to the highest aims.

He was educated by his father at Market Bosworth, and it was originally intended that he should proceed to the University of Oxford, but an invitation from his maternal uncle, John Dickinson, F.R.S., led him at the age of 17 to join the staff of John Dickinson & Co., paper-manufacturers, of Nash Mills, Hemel Hempstead (Hertfordshire). He made his home at the residence adjoining the works, a country-house, where for fifty years he lived at once the life of a country-gentleman, a man of business, a literary scholar, and a scientific investigator. Owing to the excellence of his early education, his indefatigable industry and retentive memory, his range of knowledge was extremely wide. He spoke several Continental languages as fluently as his own, was well versed in Hebrew, and always ready with an apt quotation from the Latin classics.

He had a genial gift, both of wit and humour, which gave point to many an epigram and found expression in many a polished verse. It was never used unkindly, but often enlivened the tedium of a long Council-meeting or added zest to a dinner-party. It is a pity that no Boswell was found to preserve his pithy sayings, but many will be long remembered by his friends.

Evans was early attracted to geology: when a boy of nine, he made a collection of fossils from the Wenlock Limestone of Dudley. Later, he was led by circumstances into two separate lines of enquiry—on the one hand, water-supply engaged his attention, particularly as regards the relations of rainfall, evaporation, and percolation; on the other hand, the relics of prehistoric man. It is

with the latter subject that his name will always be most closely associated by geologists.

The discoveries made by Boucher de Perthes, from 1841 onwards and first published in 1847, were received by his countrymen with incredulity, not unmixed with derision. In 1858 Hugh Falconer examined the collection which Boucher de Perthes had made at Abbeville, and on his return to England he urged Joseph Prestwich to visit the Valley of the Somme and to make a searching enquiry into the facts. Evans and Prestwich undertook this work together: they carefully studied Boucher de Perthes's specimens, examined the gravels at Amiens and Abbeville, and actually saw one of the ancient implements still embedded *in situ*. The evidence was overwhelming, and they returned to England convinced that an ancient race of men who had fabricated rude flint-implements had inhabited France contemporaneously with extinct mammals, such as the mammoth and the woolly rhinoceros. They afterwards visited Hoxne in Suffolk, where similar worked flints had been found at the end of the eighteenth century by Mr. John Frere, who had described them in a remarkable memoir, from which it appears that he fully understood their true nature. It was indeed in England that these prehistoric weapons first attracted attention, and even as early as 1715 an implement of Acheulean type had been figured by Messrs. Bagford & Hearnes. This was described by Evans before the Society of Antiquaries, of which he was a Fellow, having been elected in 1852. His paper entitled 'On the Flint-Implements in the Drift, being an Account of their Discovery on the Continent & in England' was published in the 'Archæologia' vol. xxx (1860) p. 280. Prestwich communicated his results in an independent paper to the Royal Society.

It was in the same year as Prestwich and Evans, that Gaudry visited St. Acheul: he made fresh excavations on a very extensive scale, keeping the workmen under constant observation, and succeeded in obtaining nine flints, incontestably shaped by man and associated with extinct mammals, in the Quaternary gravels. He communicated these results to the Académie des Sciences on October 3rd, 1859. It is thus just fifty years ago since Prestwich, Evans, and Gaudry succeeded in obtaining recognition for the discoveries of Boucher de Perthes, and so laid the foundations of a new and still rapidly increasing department of palæontological science.

Evans threw himself heart and soul into the advancement of

the new study; it was a task for which he was peculiarly well fitted, demanding acuteness of observation, and a rare combination of critical faculty and receptive powers: these he possessed in a high degree; neither credulous nor sceptical, he was as little likely to let slip a discovery as to be imposed upon by forgeries or simulacra. As his investigations progressed he communicated their results in numerous important papers to various scientific societies; some are to be found in our own Journal, the latest, and, as it proved, unfortunately the last, was on 'Some Recent Discoveries of Flint-Implements,' which was published in 1908 (Quart. Journ. Geol. Soc. vol. lxiv).

His great work, however, is the volume on 'Ancient Stone-Implements, Weapons, & Ornaments of Great Britain,' which was published in 1872; it was followed by a French translation three years later, and a revised and enlarged edition appeared in 1897. It is still a standard work of reference.

The collection on which this work was based was amassed by untiring efforts; whenever fresh finds were announced Evans either visited the locality and collected from it himself, or found means to acquire specimens in some other way, often through one or other of his numerous friends. He continually added to it throughout his life, so that it became one of the finest collections of its kind in the world.

Although Quaternary deposits were his chief geological study, he followed with close attention the general progress of the science, and was keenly alive to every new discovery, even when it lay apparently so far from his own special work as the *Archæopteryx* of Solenhofen or the *Palæomastodon* from the Fayûm.

Sir John Evans took an active part in the proceedings of many scientific societies, but it was our peculiar privilege to receive the largest share of his affection. His connexion with the Society commenced in 1857, when he was elected a Fellow; he was one of the Secretaries from 1866 to 1874, when he became President; his first address in 1875 was chiefly devoted to the Antiquity of Man, the second to more general questions connected with the displacement of the earth's axis and the water-supply of the metropolis. In 1880 he received the Lyell Medal in recognition of his distinguished services to geological science, especially in the department of post-Tertiary geology. He was Foreign Secretary from 1895 to 1907, and only resigned this office when compelled by an increasing infirmity.

Sir John Evans was elected a Fellow of the Royal Society in 1864, and held the office of Treasurer for twenty years. He was an Honorary LL.D. of Dublin and Toronto, Sc.D. of Cambridge, and D.C.L. of Oxford. He was also an Honorary Fellow of Brazenose College in the last-named University. In 1892 he was created Knight Commander of the Bath by Queen Victoria.

Sir John Evans was married three times; his first wife wa his cousin, Miss Dickinson. Their eldest son is the distinguished antiquarian, Arthur John Evans, famous for his discoveries in Crete.

Lady Evans, who survives her husband, is the daughter of Mr. C. C. Lathbury of Wimbledon; she is herself an accomplished classical scholar and antiquary. She has one daughter.

In Sir John Evans ripe scholarship was happily united with zeal for discovery; his learning was illuminated by his wit, and his wit was tempered by kindness of heart. He was imposing in person as he was courteous in manner, and the memory of his friendly and genial presence will long be preserved within the walls of these chambers where it was known so well.

Wilfrid Hudleston Hudleston (born Simpson), 1828–1909.—Wilfrid Hudleston Hudleston was born on June 2nd, 1828, in the city of York. He was the eldest son of Dr. John Simpson of Knaresborough, a physician whose father and grandfather had also been medical practitioners. In 1867, subsequent to his marriage with Elizabeth Ward, a representative of the second branch of the Hudlestons of Cumberland and an heiress, Dr. Simpson assumed the name of Hudleston.

It is interesting to observe that Mr. Hudleston completes the trio of distinguished geologists at the head of this list who all illustrate the influence of heredity, who were all amateurs following geology for its own sake, and who all held the office of President in this Society.

During the years 1831 to 1834 Hudleston lived with his parents at Harrogate, and it was here that he and Sorby met as playfellows. He received his early education at St. Peter's School, York, then passed on to Uppingham, and afterwards entered St. John's College, Cambridge. In his last term he attended Sedgwick's lectures, and was deeply impressed by the personality of the great geologist. After graduating in Arts in 1850, he commenced to read for the Law, and was called to the bar in 1853; but never practised. From 1850 to 1862 he was an ardent student of

ornithology, and was thus led to make long journeys over many parts of Europe and Northern Africa. From 1862 to 1867 he devoted himself to the systematic study of natural science, first at Edinburgh and afterwards at the Royal College of Chemistry in Oxford Street. He was almost equally attracted to chemistry and geology, and the choice of geology for his life's work was due to a chance meeting with Marshall Hall at Chamounix in 1866; this led to his acquaintance with John Morris, whose attractive enthusiasm proved irresistible, and in 1867 he was elected a Fellow of this Society. Hudleston's inclination was towards open-air geology, he was an ardent worker in the field, and did much to organize the excursions of the Geologists' Association: of this body he became a member in 1871. Three years later he became its Secretary, and drew up reports of its expeditions which abound in original observations. His earliest published papers were the 'Yorkshire Oolites,' which appeared between the years 1873 and 1878. His first communication to the Geological Society, made in association with J. F. Blake, was a very important memoir on the 'Corallian Rocks of England.' This masterly work is the first complete treatise on the beds which lie between the Kimmeridge and the Oxford Clay in this country.

In 1881 he was elected President of the Geologists' Association, and during his term of office delivered two addresses, one on 'Deep-Sea Investigation' and the other on 'The Geology of Palestine.' Each is a short but complete monograph, admirably succinct and clear.

In 1884 Mr. Hudleston was elected a Fellow of the Royal Society; in 1886 he was elected one of the Secretaries of the Geological Society, and in 1892 became President. The Geologists' Association made this the occasion of a congratulatory address, in which Mr. Hudleston was spoken of as the Association's 'best friend.' His addresses were devoted to an exposition of the recent work published in our Journal, the first treating of the Cainozoic and Mesozoic Eras, and the second of the Palæozoic and Fundamental Rocks and certain general questions. It was a difficult and delicate task; as he remarked, 'not unlike that of a man who tries to lift up a beehive': needless to say, it was accomplished with perfect judgement and good taste. These valuable *résumés* suggest the question whether addresses of the same nature ought not to be expected from the Presidential chair, say once in every decade.

In 1895 Mr. and Mrs. Hudleston, accompanied by Prof. J. F. Blake, sailed for Bombay: after leaving Blake at Baroda, they visited the North-West Frontier, then crossed the Punjab, journeyed up the banks of the Indus, ascended Mount Tilla, and then went on to Rawal Pindi. The observations made on this journey were published as 'Notes on Indian Geology' by the Geologists' Association in 1896.

Hudleston's *magnum opus*, which was published in 1897, is the Monograph of the Inferior Oolite Gasteropoda, a volume of 544 pages and 44 plates. It was based on a magnificent collection of several thousand specimens contained in his own museum.

In the same year as this work appeared he received the Wollaston Medal, as a well-deserved recognition of his contributions to chemical, mineralogical, palæontological, and stratigraphical geology.

In 1898 he was President of the Geological Section of the British Association at its meeting in Bristol, and delivered one of his usual thoughtful addresses on the problems presented by the geology of the surrounding district.

Amongst his latest work is a paper on the Tanganyika problem. It affords a striking illustration of his remarkable power of depicting the geology of a district which he had not visited. Its conclusions are sound, and clearly prove that the freshwater fauna of the lake is not descended from marine Jurassic forms modified in place.

From 1886 to 1901 Hudleston was one of the editors of the 'Geological Magazine.'

In 1890 he married Rose, second daughter of William Heywood Benson, of Little Thorpe, Ripon. He lived for some years at Cheyne Walk, Chelsea, but afterwards at 8 Stanhope Gardens, South Kensington, and West Holme, near Wareham.

A remarkably active and energetic man, he enjoyed fairly good health up to the last; on January 29th, 1909, after returning from a walk, he died from sudden failure of the heart.

An accurate and industrious observer, a clear thinker, as searching in criticism as he was skilful in construction, and as able in exposition as he was fortunate in discovery, he nobly maintained the traditions of the great masters in our science. In losing him we lose one of our 'best friends.'

Albert Jean Gaudry (1827–1908).—Albert Jean Gaudry was born on December 15th, 1827, at Saint-Germain-en-Laye. His

father, who was President of the Order of Advocates, and familiarly known among his colleagues as the Nestor of the Bar, had a great liking for Natural History, especially minerals, of which he had made a large collection.

After obtaining his doctor's degree in 1852 by original work in Zoology and Palæontology, Gaudry was appointed Assistant Naturalist in the Muséum of the Jardin des Plantes, and almost immediately afterwards he was entrusted with the leadership of a scientific expedition to the East. Accompanied by his friend, Damour the mineralogist, he travelled in Syria, Cyprus, Egypt, the Ionian Isles, and Greece. The results of the expedition were published under the title of 'Recherches scientifiques en Orient—Partie agricole.' On passing through Athens, he had heard of a locality where fossil bones were found in great numbers: this was Pikermi, a hamlet at the foot of Pentelicus. After his return to Paris he obtained a commission from the Académie des Sciences to make excavations at Pikermi. These were carried on under many difficulties—floods, fever, and even brigands—for several years. His account of this important work is so charming and so characteristic that a free translation may be inserted here.

'Our life in camp,' he says, 'was not without its hardships: the heat was extreme, the insects relentless. We had to rise with the sun and to work all day, without even a short siesta. The crowd of poor workmen, who came to dig, took fever instead.

'Yet, I confess, when I recall those times—the sunshine of Greece beating on my tent, the blue sky without a cloud, the marble mountains with their noble profile, and the sea of Marathon glistening in the distance—I could almost wish myself, even now that I am back in our beloved France, once again at the foot of Pentelicus.

'After all, our laborious hours were not without their moments of pleasure. We had only to find a new fossil to be inspired with fresh courage. If the day was signalized by an important discovery, we celebrated the event in the evening by a little festival. We had a skin of Greek wine, honey from Hymettus, and sometimes we broke off the branches of old pines to make a bonfire, whereon we roasted a sheep *à la pallicare*, that is whole, in Homeric fashion. When the wine had diffused its genial influence, the workmen, shepherds, and soldiers surrounded the glowing embers and started up old Albanian songs. Some of them began to dance, others giving the time by clapping of hands. If a

wandering traveller, straying by the foot of Pentelicus, had happened to catch a glimpse of our encampment, he would have fancied himself back in the time of the Greek mythology, witnessing a festival of fauns.'

Gaudry brought home to Paris a rich booty: there were several thousands of bones, representing monkeys, carnivora (among them *Machairodus*), rhinoceros, mastodons, deinotherium, hipparion, antelopes, and giraffes. In 1862 the first part of his great work on 'Les Animaux fossiles & la Géologie de l'Attique' made its appearance; it was completed in 1867.

The comparative study of these remains, in connexion with recent forms on the one hand and still older forms on the other, such as those of Sansan and Auvergne, led him to perceive that ancestral affinities could be traced in linear series. Gaudry thus became a convinced transformationist; and in this he stood for the moment absolutely alone among his countrymen, for the doctrine of Cuvier at that time still maintained its absolute sway. Under these circumstances, he greatly appreciated the following letter from Darwin, addressed to him on January 21st, 1868:—

'. . . I am delighted to hear that you intend to consider the relations of fossil animals in connexion with their genealogy: . . . your belief will, I suppose, at present lower you in the estimation of your countrymen; but, judging from the rapid spread in all parts of Europe, excepting France, of a belief in the common descent of allied species, I must think that this belief will before long become universal. How strange it is, that the country which gave birth to Buffon, the elder Geoffroy, and especially to Lamarck, should now cling so pertinaciously to the belief that species are immutable!'

Darwin's opinion of Gaudry was expressed a little later in a letter, dated September 24th, 1868, to the Marquis de Saporta, who was then tracing the genealogical relations of plants. It is as follows:—

'All the great authorities of the Institute seem firmly resolved to believe in the immutability of species, and this has always astonished me. . . . Almost the only exception, so far as I know, is M. Gaudry, and I think he will be soon one of the chief leaders in Zoological Palæontology in Europe.'

M. Gaudry now undertook to give a course of lectures at the Sorbonne: it began in 1870, and he lectured during the siege, when it rained shells in the court of the Sorbonne. At that eventful time the Professor passed his nights on the ramparts defending the gate of Châtillon.

In 1872 Gaudry succeeded Lartet in the Chair of Palæontology at the Muséum of the Jardin des Plantes. His next researches

were made at the foot of Mont Léberon, in the Vaucluse, where he obtained many new species of genera similar to those that he had found in beds of approximately the same age at Pikermi. His observations in this case forced upon him the importance of migrations, as an explanation of the apparently sudden changes in species.

Reference has already been made, in the notice of Sir John Evans, to Gaudry's excavations at St. Acheul. He continued to take an interest in Pleistocene fossils to the end of his life, and published, in conjunction with M. Marcellin Boule, who succeeded him in the Chair at the Museum, an important work on 'Matériaux pour l'Histoire des Temps Quaternaires.'

The work by which Gaudry is most widely known in this country and in France is the 'Enchaînement du Monde Animal,' the first volume of which appeared in 1878. In this he traced with a master's hand the transformations which had affected the mammals in Tertiary times. All who have made acquaintance with this work must have yielded to its charm. It was completed in 1896 by another volume bearing the title 'Essai de Paléontologie philosophique,' which contains a full development of his views.

On March 9th, 1902, he was the hero of a great ceremonial at the Muséum of the Jardin, when, amidst the rejoicings of his assembled friends, he was presented with a medal bearing his effigy engraved by the sculptor Vernon.

Gaudry resigned his Chair in 1904, and was succeeded by his distinguished pupil and devoted colleague, Dr. Marcellin Boule. He still continued, however, his work of investigation, particularly on the mammals of Patagonia which had been brought home by M. Tournouer: on this subject he left behind an unfinished memoir. Gaudry communicated one paper to the Geological Society; its subject was 'The Mammalia of the Drift of Paris & its Outskirts': it was printed in our Journal (vol. xxviii, 1872, p. 491).

Gaudry was elected a Foreign Correspondent of this Society in 1868, and a Foreign Member in 1874. The Wollaston Medal was awarded to him in 1884, as a recognition of the value of his palæontological researches and the importance of his scientific generalizations. He died on November 29th, 1908.

Gaudry was greatly loved and esteemed, not only for his scientific work, but for his high moral qualities. In the words of Prof. Boule, we may say that, if he is allied to Lamarck and Geoffroy

Saint-Hilaire by the boldness and grandeur of his philosophic conceptions, he may also claim by the elegance of his style to be the direct successor of Buffon, while in precision and lucidity he ranks with the great Cuvier.

In the death of Dr. Friedrich Schmidt of St. Petersburg, which took place on November 21st, 1908, our Society laments the loss, not only of one of its most eminent Wollaston Medallists, but of one of the last survivors of the heroic age of Geology. For the last half-century the name of Schmidt has been a 'household word' among the workers in the Lower Palæozoic rocks and fossils all the world over. His first work on the 'Silurische Formation von Esthland, Nord Livland & Œsel,' which was published in 1856, made him the chief authority on the Lower Palæozoic rocks of the Baltic Provinces of Russia; and all his subsequent career has been practically devoted to the working-out of the detailed stratigraphy and palæontology of those rocks, and to the description and illustration of their characteristic fossils.

Schmidt was the contemporary and occasional colleague of Eichwald, Pander, Keyserling, De Verneuil, Murchison, and Barrande. But in the matter of our present knowledge of the Lower Palæozoic rocks and fossils of the Russian Baltic Provinces, we might almost assert that we owe it to Schmidt's personal researches and publications alone.

In his first paper (already mentioned), published in 1856, he established the general succession; and in his paper on the 'Silurian Strata of the Baltic Provinces,' published in our own Journal in 1882, he proved that the three faunal divisions of the Lower Palæozoic rocks (Cambrian, Ordovician, and Silurian) are all present, and are collectively separable into some fifteen separate zones.

The Trilobites of the whole succession have been admirably described and illustrated by him in his great work, the 'Revision der Baltisch-Silurischen Trilobiten,' commenced in 1877, and completed two years ago. In addition, he has published monographs on the Eurypteridæ and *Leperditiæ*, and other works; and at the time of his death he had commenced a work on the Brachiopoda of the Baltic Provinces, of which he published a preliminary Note as late as May of last year.

To the last, Schmidt not only retained that youthful delight in

his work, and that love of accuracy and thoroughness which made his first memoir a classic, but retained that sympathy with younger workers which made him ever ready to aid them generously from the stores of his own knowledge. He led them enthusiastically to his own critical sections in the field, and followed their future progress in the science with keen interest. To European workers among the Lower Palæozoic rocks and fossils, Schmidt's Baltic Provinces were a land of frequent and pleasant pilgrimage, and Schmidt himself the most instructive and stimulating of guides.

Schmidt was elected a Foreign Correspondent of this Society in 1890 and a Foreign Member in 1895. He was awarded the Wollaston Medal in 1902, 'as a grateful acknowledgment of the value of his scientific researches.' But it is not by these researches alone, great as they were, that at the present moment his name will be recalled by those who knew him best. Rather will his memory be enshrined by them as that of a true geologist, quiet but deep in his enthusiasm, unremitting in his industry, thorough in his work, and heartily sympathetic with all other researchers in the same field. [C. L.]

Albert Auguste de Lapparent (1839–1908)[1].—Albert Auguste de Lapparent was born at Bourges on December 13th, 1839, and came of an old aristocratic stock. He held the first place among the students of his year when he entered the 'École Polytechnique.' From there he proceeded to the School of Mines, and in 1864 he qualified as a Government Mining Engineer. Shortly afterwards his master, Élie de Beaumont, invited him to join the staff of the Geological Survey, which had been recently organized. A part of his work in this connexion consisted of a study of the Pays de Bray in Normandy, which is a denuded dome, or a kind of diminutive Weald: it was most successfully accomplished, and very precise results were obtained by applying geometrical methods to the delineation of the outcrop of a carefully-selected thin layer of the Upper Greensand.

From 1865 to 1880 he was one of the editors of the 'Revue de Géologie'; he thus maintained a close acquaintance with the annual progress of our science, and at the same time received a

[1] I am indebted, for much of the material on which this obituary is based, to M. M. Allorge.

valuable and methodical training in dealing with and reviewing foreign publications.

In 1875, when the question of constructing a submarine tunnel was under consideration, he devoted himself to the examination of the floor of the Straits of Dover. His manner of procedure was to investigate equally the nature of both shores, and to map out the submarine stratification by means of numerous soundings made in the actual bed of the Straits. In this way he produced the first detailed geological map of a part of the sea-floor.

In 1882 he published for the first time his 'Traité de Géologie,' and the following year the 'Cours de Minéralogie.' They embody the substance of his lectures at the 'Faculté Libre des Sciences.' The former of these books was kept constantly up to date by dint of incessant toil and methodical labour. This makes the last edition one of the best existing handbooks of stratigraphical geology, and its value is enhanced by the numerous palæogeographical sketches which sum up our knowlege of the relative distribution of land and sea during the different geological periods.

In 1888 appeared the 'Géologie en Chemin de Fer,' in which the author made the first step in the study of the close connexion existing between the scenery and nature of the subsoil in the Paris Basin.

This, therefore, was the starting point of his growing interest in the new and attractive problems of Geomorphology, which culminated in the publication of the 'Leçons de Géographie Physique' in 1896.

Outside and beyond these standard text-books we find him revealing his talents as a public speaker, and as a writer in numerous papers and articles appearing in periodicals of the first class. Let us hope that we shall soon see issued a collection of these essays, perhaps together with others as yet unpublished.

It may be safely said that, had he lived a few years longer, his literary gifts would have won for him a place among the immortal forty of the French Academy. If so, he would have worthily revenged the caustic remark of the witty man of letters Töppfer, who, having met a geological party in the Alps, described it as 'a very delightful party, but for geologists only!'

It is twelve years since De Lapparent was admitted to the 'Académie des Sciences,' where he succeeded to Descloizeaux in the Mineralogical section. He had hardly entered on the duties

of Secretary to this learned body when his quite unexpected death occurred at Paris, on the 4th of last May.

De Lapparent was naturally endowed with a most pleasing and attractive manner, and none of those who came within the circle of his acquaintance could fail to respond to the charm of his personality and conversation. Those who were thus privileged will feel his loss as that of a personal friend. Our Society elected him a Foreign Correspondent in 1887 and a Foreign Member in 1897: he was one of the favourite guests at our Centenary Celebration, when we welcomed him as one of the Delegates of the Geological Society of France. His sympathetic and eloquent speeches contributed greatly to the good fellowship which united all geologists on that occasion. The speech which he delivered at the dinner given in St. John's College, after the University of Cambridge had conferred upon him the honorary degree of Sc.D., is perfect of its kind. It abounds in friendly feeling towards this country, most gracefully expressed, and is especially marked by a deep and true appreciation of the wholesome influences which attend our University life.

Harry Govier Seeley (1839–1909).—Harry Govier Seeley, son of Richard Hovill Seeley, was born in London on February 18th, 1839. A course of lectures which he attended, on Terrestrial Magnetism, first aroused his interest in Geology. This was deepened by a study of Lyell's 'Principles.' After attending lectures at the Royal School of Mines, he was admitted to Sidney Sussex College, Cambridge; and, shortly after entering into residence, he was invited by Prof. Sedgwick to act as Assistant in the Woodwardian Museum. There he found awaiting determination the rich fauna which had been obtained from the 'coprolite-pits' of the Cambridge Greensand. He entered enthusiastically into the work, and prepared a descriptive account, which was published by the University Press in 1869, as a 'Catalogue of the Fossil Reptilia in the Woodwardian Museum.' He paid great attention to the fragmentary remains of the flying reptiles; and his account of these was given in a volume entitled 'Ornithosauria,' which was published by the University Press in 1871. He occasionally lectured in the Museum, sometimes as a substitute for Prof. Sedgwick, sometimes independently, as when he gave popular courses to young people, which were always greatly appreciated owing to the simplicity and originality of their style.

On the death of Sedgwick in 1873 he left Cambridge and returned to London, where he engaged for a time in private tuition.

In 1876 he was appointed Professor of Geography in King's College, London, and succeeded in making geography interesting by providing its facts with geological explanations. In the same year he became Professor of Geography and Geology in Queen's College, London. In 1890 he was appointed Lecturer in Geology and Mineralogy in the Royal Indian Engineering College at Coopers Hill, and succeeded Martin Duncan as Professor in 1891, a post which he held until the College was closed in 1905. In 1896 he succeeded Wiltshire as Professor of Geology and Mineralogy at King's College, London.

In 1885 he founded the London Geological Field Class, to which he acted as leader for 21 years. In connexion with this he wrote a very useful handbook on the geology of the London district, published in 1891.

Seeley possessed a wide knowledge of Geology, and was keenly interested in its principles; but his special study, and that on which his reputation will depend, was the fossil Reptilia. In order to gain a knowledge of these at first hand, he visited nearly all the principal museums in Europe, examined Permian remains in Russia, and the reptilian deposits of the Karroo in South Africa. The reptiles of the Karroo were subsequently described in a series of masterly memoirs, which were published in the 'Transactions' of the Royal Society between the years 1889 and 1895. *Pareiasaurus* and *Cynognathus* will always remain associated with his name. His contributions to our Journal are numerous and important; the first appeared in 1863, the last in 1900. Seeley was the author of numerous books; the first volume of Phillips's 'Manual of Geology' was revised and almost entirely rewritten by him: the revised edition was published in 1884. He wrote 'The Freshwater Fishes of Europe' (1886), 'Factors in Life' (S.P.C.K., 1887), 'Fossil Reptiles' (1887), 'Story of the Earth in Past Ages' (1895), and 'Dragons of the Air' (1901): in the last-named he expressed his mature views on the flying reptiles which had first engaged his attention 30 years before.

He was elected a Fellow of this Society in 1862, served several terms on the Council (1879–84, 1886–90, 1898–1904), and was Vice-President in 1900–1902. He received an award from the Murchison Fund in 1875 and the Lyell Medal in 1885. He was

elected a Fellow of the Royal Society in 1879, and a Fellow of King's College in 1905. He was Honorary Member of several Foreign societies, among them the Academy of Science in Philadelphia, the Imperial Society of Naturalists in Moscow, and the Imperial Academy of Sciences in St. Petersburg.

In 1872 Prof. Seeley married Eleanor Jane, second daughter of William Mitchell, St. George's Lodge, Bath. He died, after much suffering, at his residence, 2 Holland-Park-Court, W., on January 8th, 1909.

Seeley was a man of marked individuality, very independent in opinion and original in thought. In his later years an increasing deafness deprived him of the full enjoyment of conversation; but those who remember him in his earlier days will retain a vivid impression of a warm-hearted comrade, a lively raconteur, ready with quip and jest, yet much in earnest and profoundly occupied by the deeper problems of human existence.

Alfred William Howitt, C.M.G., Sc.D. (1830–1908)[1].—Alfred William Howitt was born in 1830; his parents were William and Mary Howitt, who jointly and severally made numerous contributions to the poetry and prose of the last century. Some of their poems at one time bid fair to retain a permanent place in our literature. He was educated partly in Germany and partly at University College, London. He married Maria, daughter of Mr. Justice Boothby, of the Supreme Court of South Australia.

Dr. Howitt added considerably to our knowledge of the native tribes of Australia, his most important works being: 'Kamilaroi & Kurnai' and 'The Native Tribes of South-East Australia'; he also contributed papers to the Transactions of the Royal Society of Victoria and the Proceedings of the Australasian Association for the Advancement of Science. In 1876 he communicated to our Society a paper on the Devonian Rocks of North Gippsland. When Burke and Wills failed to return from their disastrous expedition, Howitt was appointed leader of the party sent from Victoria in search of them.

Dr. Howitt held several important offices in Victoria, and discharged their duties with distinguished success. A ready perception and sound judgement made him an admirable man of

[1] In the preparation of this obituary I have obtained valuable information from Prof. A. Liversidge, F.R.S.

affairs. He was a delightful companion, concealing beneath a quiet and unassuming manner a remarkably sympathetic disposition. He died on the 9th of March, 1908.

Charles Louis Perceval de Loriol-Le Fort (1828–1908).—Perceval de Loriol was born in Geneva in 1828. Destined by his father for agricultural pursuits, he began life as a farmer soon after leaving school, where he had received a classical education. An irresistible inclination towards natural science soon led him to abandon this career, and he returned to Geneva to pursue the study of zoology, and palæontology in particular. His teacher, F. J. Pictet de la Rive, was an ardent student of the Mesozoic faunas of Switzerland and published, in collaboration with his pupils, the well-known 'Matériaux pour la Paléontologie de la Suisse'. The first fruits of De Loriol's work was a joint memoir with De la Rive on the fossils of the Neocomian limestones of the Voirons, which appeared in 1858. From that time to the end of his life the palæontology of Switzerland was the one object of his study, memoir after memoir flowed from his pen, and the proof-sheets of the last that he was ever to write was given to the editor of the 'Revue suisse de Zoologie' but a few days before his death. We owe the foundations of all exact stratigraphical knowledge of the Upper Jurassic in Switzerland to his careful specific descriptions. The Jurassic, Cretaceous, and Tertiary echinoderms of Switzerland were very completely investigated by De Loriol, and are described in his 'Échinologie helvétique,' published in two large volumes, between the years 1872 and 1875. He also wrote the volume of the 'Paléontologie française,' treating of the Jurassic Crinoids, and a monograph of the Tertiary Echinoids of Egypt, and described the echinoderms of the Secondary and Tertiary rocks of Portugal.

De Loriol founded the Société Paléontologique suisse; he was the perpetual editor of its publications, and administered almost all its affairs.

He was elected a Foreign Correspondent of our Society in 1894, and he died on December 23rd, 1908, in the 81st year of his age.

De Loriol restricted his attention with unwavering devotion to systematic palæontology; in this field he was an exact and conscientious observer; outside it his interests were limited, he cared little for theories of development, the building-up of genealogical

trees, or even for questions of stratigraphy arising directly out of his own studies. His industry was remarkable and not less so his modest and unselfish disposition, which impressed all who were brought in contact with him.

Joaquim Filippe Nery da Encarnaçao Delgado (1835–1908).—General Delgado was born at Elvas on May 26th, 1835. At the age of nine years he entered the Military College of Lisbon, and, after completing his studies, obtained an appointment in the Department of Public Works. One of his first duties was to serve on a Commission appointed to devise means for the regulation of the River Mondego.

In August, 1857, he was attached to the Geological Survey (just one month after its creation) and served under Carlos Ribeiro, until its dissolution in 1868, when he was entrusted with special studies, which were in fact a continuation of the work he had done on the Survey. When the Geological Survey was re-established in 1869, as a section of the Department for Geodesic Works, Delgado was re-appointed, and in 1882 he succeeded Carlos Ribeiro as Director, a post which he held until his death.

Delgado greatly enlarged our knowledge of the Palæozoic Systems of Portugal, particularly the Cambrian and Silurian, and we are indebted to him for several excellent memoirs on the Lower Palæozoic faunas. He was greatly interested in questions relating to prehistoric man, and made a detailed investigation of the cave of Furninha. After an examination of the sections at Otta, he announced in 1889 that he had not been able to discover in these Tertiary deposits any flints showing signs of human workmanship.

General Delgado was part author of the Geological Map of Portugal, on the scale of 1 : 500,000.

He was elected a Foreign Correspondent of our Society in 1887, and a Foreign Member in 1899. In the summer of last year, after laborious work in the field, he fell ill with congestion of the lungs; from this he never recovered, and died on August 3rd, 1908.

W. Jerome Harrison (1845–1908).—W. Jerome Harrison was born in 1845 at Hemsworth, near Doncaster. He was destined for the teaching profession, and passed through the Practising Schools, Westminster, during the years 1858–63, completing his training

at Cheltenham Training College in 1864–65. For the next six years he was headmaster of various elementary schools.

In 1872 he was appointed chief Curator of the Leicester Corporation Museum, and while he held this office he attended during parts of four years courses at the Normal School of Science, South Kensington.

In the year 1880 he received the appointment of Chief Science Master to the Birmingham School Board, in 1902 he was made Chief Science Demonstrator, and until the day of his death, June 6th, 1908, all the scientific instruction of the Birmingham elementary schools was carried out under his direction.

Very early in life he contracted a love for scientific study and research, especially in geology. One of his first geological papers was on his discovery of Rhætic Beds in Leicestershire: this was published in our Quarterly Journal in 1876. He followed up this work by papers on the geology of various parts of Leicestershire (Charnwood Forest, Brazil Wood, etc.), contributed to various local and other societies. After coming to Birmingham he took up for a time the investigation of the ancient rocks of the district, summarizing his work and conclusions in his paper on 'The Pre-Carboniferous Floor of the Midlands' (1885), for which the Midland Union of Naturalists' Societies awarded him their Darwin Medal. We also owe to him the first discovery of rocks of Cambrian age at Dost Hill (1886).

As early as 1878 he had begun to study with ardour the Glacial deposits of the Midlands. From that time onwards his affection for this branch of geology increased. Long before his death he had made himself one of the acknowledged authorities on the subject. At this he worked for some time in company with the late Dr. Crosskey, but of recent years practically alone. His first contribution was a scheme for the systematic examination of these deposits. Later on he dealt with the Quartzite-Pebbles in the Drift (1883), the Glaciology of the Yorkshire Coast (1895), and the best-known of his series was his Bibliography of Midland Glaciology.

He also assisted Dr. Crosskey in bringing out the late Carvell Lewis's papers on the Glacial Geology of Great Britain & Ireland (1894), and he contributed the chapter on the Ancient Glaciers of the Midlands to the Sketch of the Geology of the Birmingham District, published by the Geologists' Association in 1898.

He was elected a Fellow of our Society in 1876, and was awarded the Barlow-Jameson Fund in 1890.

Harrison was a skilful amateur-photographer, and to his initiation was largely owing the foundation of the well-known Midland Photographic Survey. He was also one of the first in the Midlands to make use of photography for the purpose of illustrating scientific teaching, lectures, and papers. When the history of the comparatively recent application of photography for the teaching and illustration of Geology comes to be written, Harrison's name will stand in the first rank among those of the most enthusiastic and active local pioneers. The National Collection of Geological Photographs contains some hundreds of examples of his work.

Harrison was the author of the well-known 'Geology of the Counties of England & Wales' and of various text-books on geology, geography, etc.

He took every opportunity as a teacher to inculcate the love of science among his many pupils, and he was one of the first to organize geological and geographical excursions among them for the purpose of studying the actual phenomena in the field. Although throughout life one of the busiest of men, he found time to join frequently and heartily in the work of the various local scientific societies: whether as Secretary, President, or Lecturer, his interest and enthusiasm were infectious and stimulative. [C. L.]

Joseph Lomas (1860–1908).—Joseph Lomas was educated at the Royal College of Science, and on the completion of his studies was appointed Science Demonstrator to the School-Board, and subsequently Special Lecturer in Geology in the University, of Liverpool. Soon after taking up his residence in that city he entered University College as a research student, and undertook an investigation of the marine Polyzoa; among numerous other interesting observations, he recorded the occurrence of calcareous spicules in the Ctenostomata. He took part in submarine explorations of the Irish Sea, and in connexion with the Liverpool Marine Biology Committee wrote an account of the deposits forming its bed. A collection in illustration of the results of this research is preserved in the Museum of Practical Geology, Jermyn Street. At the same time he engaged in researches into the Glacial phenomena of the neighbourhood of Liverpool and of several areas in North Wales—work that was recognized by this Society by an Award from the Lyell Fund. He also wrote on the basalts of Mull, the fossil plants of the Carboniferous, the coasts of Lancashire and Cheshire, and on Comparative Lithology. Of late years he directed his attention more especially

to the British Trias. In 1903 he was appointed Secretary of a Committee of the British Association to investigate the fauna and flora of the Trias of the British Isles, which has ever since published an annual report; the sixth, and unfortunately the last written by him, was presented to the meeting in Dublin last year.

At the same meeting a Committee was appointed, with Lomas as secretary, to investigate some salt-lakes near Biskra, with a view to throwing additional light on the British Trias. A few months after his appointment, Lomas started with great enthusiasm on this expedition; but, while proceeding to Biskra, the train from Algiers to Constantine was wrecked in a terrible accident, and Lomas was found amongst the killed. This was on December 16th, 1908.

He was a Member of the Liverpool Geological Society, and was elected its President in 1897 and 1898, and again in 1909 in view of the Jubilee of the Society. He was appointed secretary to Section C of the British Association in 1899, and held that office up to the time of his death. Lomas was elected a Fellow of the Geological Society in 1897, the year in which he received the Lyell Award. Some of his papers have appeared in our Journal, and one in the Proceedings of the Royal Society; but the majority are printed in the Proceedings of the Liverpool Geological Society.

Lomas was fully alive to the importance of travel: he visited Switzerland several times with the view of studying glaciers, and accompanied the British Association in its journey through Africa in 1905, making the fullest use of his opportunities in the observation of desert-phenomena.

His modest, earnest, unaffected, and amiable disposition had endeared him to a large circle of friends.

Jacob Hort Player (1834–1908).—Jacob Hort Player, born on December 18th, 1834, was the son of a chemist living at Frome in Somerset. While he was still a child, his father retired from business and removed to Devizes, where young Player was educated. After leaving school he worked with chemists at Bedford, London, Reading, and Weymouth, taking the medal of the Pharmaceutical Society in 1854. On leaving Weymouth he joined the well-known firm of Albright & Wilson, manufacturers of phosphorus, at Oldbury in Worcestershire, as analytical chemist, and so improved their methods of working that he soon became a partner in the firm. On retiring from business he interested himself in the analysis of silicates, and thus came into

contact with geologists. He directed his attention especially to accelerating the processes involved in silicate-analysis; and, although he was always more interested in doing work than in publishing the results, he was induced to communicate a paper to the Birmingham Meeting of the British Association in 1886. This paper, on 'An Accurate & Rapid Method of Estimating the Silica in an Igneous Rock,' was published *in extenso* in the Report of that meeting.

Mr. Player was ever ready to assist geologists by analysing rocks, and the following papers, published in our Quarterly Journal, contain some of the results of his work:—'On a Phosphatic Chalk with *Belemnitella quadrata* at Taplow'[1]; 'On the Plutonic Rocks of Garabal Hill & Meall Breac'[2]; 'On the Banded Structure of some Tertiary Gabbros in the Isle of Skye'.[3]

During the last years of his life he interested himself in photography and perfected a process, known as Playertype, for copying engravings and maps by contact-printing without allowing light to pass through the object to be copied. He died on February 24th, 1908. [J. J. H. T.]

Bennett Hooper Brough (1860–1908).—Bennett Hooper Brough was born at Clapham in 1860; he was the eldest son of John Cargill Brough, F.C.S., who was himself a man of considerable literary and scientific ability. He received his early education at the City of London School, and afterwards studied first at the Royal School of Mines, London, and then at the Royal Prussian Mining Academy at Claustal. In 1882 he was appointed Assistant to Sir Warington Smyth, and in 1886 Instructor in Mine-Surveying at the Royal School of Mines; in 1893 he became Secretary to the Iron and Steel Institute, a post which offered ample opportunity for the exercise of his varied and brilliant endowments. He was particularly successful in organizing the foreign meetings of the Institute, and, in recognition of his services in connexion with the meeting in Stockholm, he was created a Knight of the Order of Wasa by the King of Sweden and Norway. His labours on behalf of the Institute terminated only with his death, which took place after a short illness on October 3rd, 1908.

Mr. Brough, though a prolific writer, did not communicate any

[1] A. Strahan, vol. xlvii (1891) p. 364.

[2] J. R. Dakyns & J. J. H. Teall, vol. xlviii (1892) p. 115.

[3] Sir A. Geikie & J. J. H. Teall, vol. l (1894) p. 653.

papers to our Society. His best-known work is a volume on Mine-Surveying, published in 1888, which has now reached the thirteenth edition. In 1907 he published a revised edition of Sir Clement Le Neve Foster's 'Ore & Stone-Mining.'

Mr. Brough was a man of great ability and indefatigable industry, ardently interested in his work and generously appreciative of the work of others.

Sir Thomas Wardle (1831–1909).—Thomas Wardle was born at Leek, on January 26th, 1831. He was educated at the local grammar-school and at Macclesfield. At an early age he entered into business connected with the silk-industry, which he afterwards did so much to promote. He was the first to discover a satisfactory process for dyeing the wild tussore-silk of India; he was commissioned on several occasions by the Government to investigate the sericiculture of India, and he revivified the moribund silk-industry of Kashmir. He wrote numerous works on sericiculture and silk-weaving—subjects on which he was the acknowledged authority. 'Kashmir and its Silk-Industry' appeared in 1904. He was President of the Silk Association of Great Britain & Ireland, and honorary expert on silk to the Imperial Institute.

In 1879 he was appointed Chevalier of the Legion of Honour, and was invested with the Knight Commandership of the Indian Empire in 1897.

Sir Thomas was elected a Fellow of the Geological Society in 1863; he was a member of the Council of the Palæontographical Society, and more than once President of the North Staffordshire Naturalists' Field-Club. He was keenly interested in the geology of the country around Leek, and wrote several papers on it, of which 'The Geology of the Neighbourhood of Leek' (1863), 'The Geology of the Roaches' (1868), and 'Limestone, its Occurrence, Nature, & Origin' (1873), are best known. When the Geologists' Association visited North Staffordshire, in 1890, he acted as Director on some of the excursions, and delivered an admirable address on the Yoredale Rocks and the Carboniferous Limestone. He was the first to discover the microscopic quartz-crystals which occur in the limestone to the extent of 0·6 per cent. of its weight.

He married, in 1857, Miss Elizabeth Wardle, who died in 1902; and he had a family of nine children. He died on January 5th, 1909.

LORD AMHERST OF HACKNEY (1835–1909).—William Amhurst Tyssen-Amherst, first Lord Amherst of Hackney, was the son of Mr. William George Tyssen Tyssen-Amherst, of Didlington (Norfolk), by Mary, daughter of Mr. Andrew Fountaine, of Narford Hall, Norfolk. He was born in 1835, and was educated at Eton and Christ Church, Oxford. He married in 1856 Margaret Susan, a Lady of Justice of the Order of St. John of Jerusalem, only child of Admiral Robert Mitford, of Hunmanby Hall (Yorkshire), and of Mitford Castle (Northumberland). He died on January 18th, 1909.

Lord Amherst was a great collector of rare and interesting books and manuscripts, tapestries, antique furniture, and other works of art. He travelled a great deal in the East, and was almost as famous for his collection of Egyptian antiquities as for his china and books.

HENRY ALBERT MANGLES (1834–1908).—Henry Albert Mangles, of Littleworth Cross, near Farnham, died on the 5th of February, 1908, aged 74. After a most distinguished career in India, where he was Accountant-General of Bengal, Madras, Bombay, and Burma, and at one time Comptroller-General, he returned home and was elected a Fellow of our Society in 1890.

Though he did not contribute to the publications of the Society, he was very much attached to geology and a keen collector of flint-implements. He was well known at the Geologists' Association as a frequent attendant at the long Excursions. He twice acted as Director on the occasion of excursions to Farnham, and on each occasion invited the members to his house, where he exhibited a series of implements from the Farnham Gravel.

Mr. Mangles was well known to horticulturists as a most successful grower of Himalayan Rhododendrons, and on more than one occasion received awards from the Royal Horticultural Society.

[R. S. H.]

At our last Anniversary the President reviewed the history of our Society and recounted the achievements of our Science. He bade farewell to the old century: it is for us to welcome the new. If the past had its triumphs, the present has no less its problems. New peaks rise before us, some close at hand and sharply defined, others more remote and as yet but dimly perceived: many a stiff and exhilarating climb is in prospect.

Of the more immediate problems that relating to geological time is one of the most important, and I propose to make it the centre about which this rather discursive address will revolve.

But, before entering into scientific discussion, there is one event in the recent history of the Society to which I would beg your permission to allude. Since vacating the Chair last year, Sir Archibald Geikie has been elected to the Presidency of the Royal Society. This is the first time that a geologist has been called to fill that illustrious office, and we may fairly regard the honour as one which casts on us as a Society some reflected beams. I feel persuaded beforehand that you will authorize me to offer the congratulations of the Society to the new President, and to express the hope that he may live long to exercise his sway with that accustomed genial wisdom which has conduced so much to our own happiness and prosperity.

The Position of Geology among the Sciences.—It has sometimes happened, on occasions like the present, that your President has taken the opportunity to lay before you his views as to the true aims and scope of our Science; if, then, I now offer a few brief remarks on this subject, I shall at least have the sanction of good example.

When Geology first started on her career, it was with the desire, conscious or unconscious, of discovering how the world was made. Since then, as she has progressed, she has extended the limit of her enquiries, and now holds all purely terrestrial phenomena as subjects proper to her study. No question that can be asked about the earth lies outside her province. That this was her predestined position will be readily perceived if we picture to ourselves the classification of the sciences, somewhat as it was conceived by Herbert Spencer. First, and seated above all, breathing the rare air of the empyrean, are Logic and Mathematics, concerned solely with abstract ideas and their relationships; next, in a lower heaven, come Chemistry and Physics (using these terms in their

very widest sense)—sciences which, beginning with the study of natural phenomena, conclude with the formulation of abstract laws; and last, in contact with the solid ground, come three concrete sciences, seated, as it were, side by side; on the one hand Astronomy, on the other Biology, and between them a science which restricts its studies to a single planet, the Earth on which we dwell. If this science had no name we should be compelled to invent one for it: if its seat were not occupied, Geology would stand waiting to be enthroned. Here then we salute our science, seated in the midst, in close companionship with Astronomy and Biology, ministered to by the higher sciences above.

By this central position Geology is peculiarly favoured; it brings her into close conversation with all the other sciences, and a cross-fertilization of ideas thus results which is prolific in fresh discoveries. It is the privilege therefore, as it is the duty, of the geologist to increase as far as possible his acquaintance with the whole realm of science; it is, indeed, in the application of this knowledge that his own special work consists. A mathematician may be a master in his own subject, and may yet without reproach boast of very little acquaintance with any other branch of knowledge; but a geologist who is entirely ignorant of mathematics is only half educated. Great investigators in Physics have been known to display an amazing want of familiarity with the rudiments of Chemistry, but a geologist must be at least well grounded in both these subjects, and at the same time it is certain that without some real knowledge of Astronomy and Biology he will not be able to push his enquiries very far.

The only approach to Geology lies through the other sciences and endeavours to enter in some other way are responsible for much of the pseudoscience that has been perpetrated in its name.[1]

If we have rightly conceived the position and external relations

[1] In making these remarks I have not the least desire to participate in a controversy which now occupies the minds of some of our teachers. A rudimentary knowledge of chemistry and physics will carry the beginner a long way, and the best endowment of the geological surveyor is a native gift for geometry. At what stage geology should enter into the regular course of school-teaching is a question to be decided by circumstances. There is no reason why the study in the field should not be commenced at a very early age, as soon, that is, as a boy begins to display an interest in out-of-door phenomena. This sort of geology may provide an interesting variation to birds'-nesting and butterfly-collecting. In any case, it is better for the boy than to be compelled to take part in games which he detests.

of geology as a whole, we may next turn to its contents. These are so numerous and manifold as to render some kind of classification necessary, and when we begin to attempt this we perceive that geology is indeed a whole group of sciences rather than a single one. A fundamental subdivision might first be made into morphology and physiology; this would perhaps commend itself as the most philosophical, but in practice it would certainly prove the most inconvenient. Our best course is to accept such subdivisions as have already been brought into existence in the course of a natural evolution. Thus we have first geodesy, which studies the morphology of the earth as a whole: one of the latest contributions to this subject is Prof. Love's harmonic analysis of its general form. No science is occupied exclusively with the study of the activities or movements of the earth as a whole, and as a matter of convenience geology borrows her knowledge of this subject from astronomy. Passing next to the earth in its parts we have meteorology, which studies the morphology and physiology of the atmosphere; hydrography, which similarly studies the hydrosphere. The superficial features of the lithosphere belong to geography; its gross anatomy, to what, for want of a better word, we must term geognosy; its minute anatomy, and—may we say histology?—, to petrography and mineralogy. There is, however, a physiological as well as a morphological side to each of these sciences; and the study of some special kinds of activity has acquired such importance as to require separate recognition, as, for instance, in the case of vulcanology and seismology.

Morphology and physiology are not the only two aspects under which the material for our study presents itself, there is a third, related to time; for the existing state of the earth is only the last of a long succession of states through which it has passed in the course of development. Development, in relation to the organic world, was regarded by Huxley as a subdivision of morphology; but, on reflection, it will be found to be equally concerned with physiology, for each successive state is as much characterized by its activities as by its form, although the form is usually more accessible to study. The sciences so far recognized which relate to development are palæogeography and cosmology.

So far we have made no mention of palæontology, yet geology has taken this subject under her ægis, and it is unquestionably one of her offspring. It has been asserted, notwithstanding, that palæontology has no place in our science, but belongs wholly to biology,

falling under the two heads of morphology and distribution. From this point of view, we apply our knowledge of palæontology to geological problems, just as we apply our knowledge of any other science, but it remains a branch of pure biology none the less. Nothing could be more exact, yet there is good reason why the geologist should devote himself to a study of fossils, and we may hope that palæontology will receive, not less, but even more attention from us in the future than it has in the past. There is no other science which can speak with such authority on the past stages in the evolution of the organic world. It is the geologist who finds the fossils, and in his case the rule of 'findings keepings' can be employed without contravening any rule of ethics. It is the geologist also who elucidates the stratigraphical facts by which the chronological and chorological distribution of the fossils is determined. His interest in these objects is closer, and his zeal in their investigation more ardent, than that of the pure zoologist. Logically we are confronted with alternatives: if the zoologist engages in this work he must become more or less of a geologist, if a geologist he must become more or less of a zoologist; so far the latter alternative seems to have been generally accepted and with very fortunate results. If, as I am sure we shall wish, this arrangement is to continue, it is imperative to cultivate a close acquaintance with animal and vegetal morphology.

The question of geological time has ceased to be made a cause of reproach to us, and we no longer are suspected of an overdrawn account in a metaphorical bank of time: indeed, since physics, in the language of the Stock Exchange, has forsaken its rôle of 'bear' for that of 'bull,' we seem rather to be threatened with the novel embarrassment of having more time on our hands than we know how to dispose of.

The Rigidity of the Earth.—Lord Kelvin's argument as to time, now that we can impartially survey it, is found to have exercised a very salutary discipline, and it still remains valid in relation to the factors it involves. There is one assumption on which it rests that has recently received the fullest justification, I allude to the asserted rigidity of the interior of the earth. This was something more than an assumption at the time it was made, for it rested on an argument drawn from the tides, which would have had greater force if it had been able to command a larger array of observational data. The investigation of the fortnightly tides forms indeed a

very interesting chapter in the history of mathematics, as applied to a geological problem; after encountering and overcoming numerous difficulties it has at length reached a successful conclusion, and Lord Kelvin's original contention that the earth is almost as rigid as a globe of steel, is found to have been an under-estimate rather than an over-estimate of the fact.

Fresh light was thrown on this question in 1900 from an unexpected quarter. Up to that time, notwithstanding a vast accession of novel and precise observations, the view which found general acceptance with respect to the nature of seismic waves was that of Mallet, who regarded them as wholly compressional. That distortional waves may be involved had been suggested by Wertheim in 1849, and maintained by Cancani in 1894, but the merit of rightly identifying such waves belongs exclusively to R. D. Oldham,[1] who attributed a distortional nature to the movements of the second phase: those of the first phase being compressional, and the large waves of the third phase, superficial, and possibly of the same nature as what are known as Rayleigh's waves.

Distortional waves, however, cannot be propagated otherwise than through a solid medium, and consequently, since in the case of great earthquakes such waves actually pass right through the substance of the planet, from the seismic focus to its antipodes, it follows necessarily that this substance must on the whole be solid.

Love[2] has carried the argument a step further, and from calculations based on the velocity of the waves combined with the assumption of uniform density, has arrived at the conclusion that the seismic rigidity of the earth must be about as twice as great as that of steel, and its compressibility (linear elasticity) about half as great. Wiechert, making a different assumption as to the density, obtains a rigidity four times as great as that of steel, and a compressibility more than four times less.

Thus we seem to have arrived at something like demonstrative proof. Our conclusion entirely depends, however, on the truth of the fundamental proposition, *i.e.*, that the waves of the second phase are in fact distortional. This has been challenged by the Rev. Osmond Fisher, whose arguments, however, by their very

[1] R. D. Oldham, 'On the Propagation of Earthquake-Motion to Great Distances' Phil. Trans. Roy. Soc. ser. A. vol. cxciv (1900) pp. 135–74.

[2] A. E. H. Love, Phil. Trans. Roy. Soc. ser. A. vol. ccvii (1907) p. 215.

ingenuity suggest doubts as to their validity. Wiechert,[1] on the other hand, definitely asserts that observations made with a vertical seismometer show 'that the movements of the first phase are longitudinal, and of the second phase transverse, waves.' Observations of a less direct kind made by Omori also confirm Oldham's view. Thus our conclusion is fully sustained. But our knowledge concerning the internal state of the earth does not rest on these arguments alone; recently, by means of observations made on horizontal pendulums, a method which was unsuccessfully employed by Sir George Darwin many years ago, Hecker[2] has obtained a measure of the amount of deformation suffered by the earth under the influence of the sun and moon. This is an achievement which may be counted as one of the greatest triumphs of the present century. From December 1st, 1902, to April 30th, 1905, a continuous record was obtained of the movements of a pair of horizontal pendulums mounted in a closed chamber excavated from the side of a well at a depth of 25 metres below the surface of the ground. Observations could be made outside the chamber and at some distance from it. The curve constructed from the records is shown in fig. 1, p. lxxxvii. If the interior of the earth were fluid, the area of this curve would have been nil; if it were absolutely unyielding, the curve would have coincided with the outer ring. As it is, the actual movement of the pendulums is about two-thirds of the amount that it would have been if the earth were absolutely rigid. Hecker concludes from this that the body of the earth behaves very much as it would do if it consisted entirely of steel.

Again, the terrestrial poles, as is now well known, suffer a slight displacement, and describe a closed curve about 20 metres in diameter, in a period of 427 days. Astronomers, assuming an absolutely rigid earth, have calculated this period and arrived at 305 days as the result. It was suggested by Newcombe that the discrepancy might be due to a defect of rigidity; and, on repeating the calculations, with this point in view, Hough[3] found an elastic yielding such as would result if the earth consisted of steel.

Finally Love,[4] combining the data afforded by this phenomenon

[1] E. Wiechert, 'Die Erdbebenforschung, ihre Hilfsmittel & ihre Resultate für die Geophysik' Physikalische Zeitschrift, 1908, pp. 36–47.

[2] O. Hecker, 'Beobachtungen an Horizontal Pendeln ü. d. Deformation des Erdkorpers, &c.' Veröffentl. d. k. Preuss. Geodätisch. Inst. n. s. No. 32, 1907.

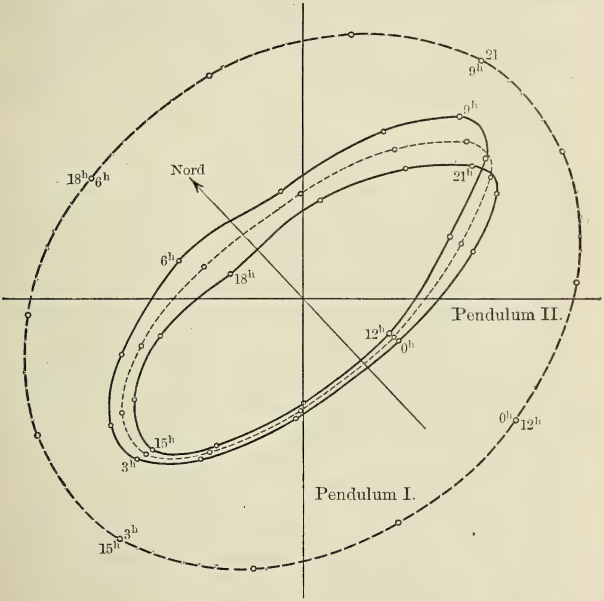
[3] S. S. Hough, 'The Rotation of an Elastic Spheroid' Phil. Trans. Roy. Soc. ser. A. vol. clxxxvii (1896) pp. 319–44.

[4] Love Proc. Roy. Soc. ser. A. vol. lxxxii (1909) pp. 73–88.

with those obtained by Hecker, has arrived at a more exact estimate of the amount of elastic yielding, and finds that it is much less than would occur in a similar globe of steel.

Thus, through the shifting sands of an ancient and prolonged controversy, *terra firma*, indeed *terra firmissima*, has at length been reached.

Fig. 1.—*Variation of the vertical under the influence of the moon.*



Continuous lines represent observed lunar curves; the inner broken line represents the observed semi-diurnal curve; the outer broken line represents the theoretical lunar curve for an absolutely rigid earth.]

A great future awaits seismic research. As Benndorf[1] happily remarks, the sensitive instruments now employed to register the movements of an earthquake are to the geologist what the spectroscope is to the astronomer: with the one we explore the depths of

[1] H. Benndorf, Mitth. Geol. Gesellsch. Wien, vol. i (1908) p. 336.

space, with the other the internal constitution of our planet, and in each case the message to be deciphered is brought to us by elastic waves.

Already the obscure signs of a subdivision into parts, to which Milne and Oldham have called attention, are beginning to acquire greater definition. As a result of his latest seismological investigations, Wiechert[1] concludes that the earth consists of a metallic kernel with a density slightly over 8, surrounded by a stony crust, having a mean density of 3·4 and a thickness of 1500 kilometres; he regards this as a striking confirmation of a view to which he had been led by other considerations so long ago as 1896. The crust itself he regards as divided into two sheets by a more yielding intermediate layer, which occurs at a depth of from 100 to 200 kilometres.

Geological Time.—It is but a few years since the discovery of a long unsuspected source of radiate energy existing within the earth's crust immensely widened the possible limits of geological time.[2] The quantitative experiments of Mr. Strutt lead us to suppose that the liberation of this energy does not continue very far below the surface; it would seem to cease at a depth of about 40 miles; the change of properties conjectured by Milne to occur at this depth and the more yielding layer inferred by Wiechert may eventually be found to stand in some connexion with this limit.

Much constructive work based on the properties of radium is now in progress.[3] Mr. Strutt[4] in particular is engaged in an endeavour to apply certain of its transformations to the determination of a chronological scale. One of the products of the disintegration of radium is helium, which is evolved at a uniform rate, and thus affords a means of measuring time. Let us suppose that the radium which enters into the substance of a mineral was introduced contemporaneously with its formation, and that the helium subsequently generated has been unable, under natural conditions, to escape. If,

[1] E. Wiechert, 'Die Erdbebenforschung, ihre Hilfsmittel & ihre Resultate für die Geophysik' Physikalische Zeitschrift, 1908, pp. 36–47.

[2] J. Joly, 'Radium & the Geological Age of the Earth' Nature, vol. lxviii (1903) p. 526; R. J. Strutt, 'On the Distribution of Radium in the Earth's Crust, & on the Earth's Internal Heat' Proc. Roy. Soc. ser. A. vol. lxxvii (1896) p. 472.

[3] J. Joly, 'Uranium & Geology,' Presidential Address to Section C, Brit. Assoc. 'Nature' vol. lxxviii (1898) p. 456.

[4] R. J. Strutt, Proc. Roy. Soc. ser. A. vol. lxxxi (1908) p. 272.

after the expiration of some unknown period, the investigator should be able, under the conditions which he can command in the laboratory, to liberate the helium and to determine the ratio of its mass to that of the radium, he will then be provided with the data required to determine the time which has elapsed since the first formation of the mineral, presuming of course that he knows the rate at which the helium is generated. The problem is complicated by the fact that in the long run it is not so much the radium, as the uranium from which it is derived, that has to be taken into account: a fact of importance from more than one point of view.

A preliminary investigation, for which phosphatic nodules furnished most of the material, afforded Mr. Strutt the following results:—

	Years.
Phosphatic nodules from the Crag	225,000
,, ,, Upper Greensand	3,080,000
,, ,, Lower Greensand	3,950,000
Hæmatite overlying Carboniferous Limestone	141,000,000

Mr. Strutt regards these periods as the minimum ages, since some of the helium may have escaped by natural leakage. On the other hand, there is a possibility, suggested by Prof. Joly, that an absorption of radium may have taken place. This may easily have exhausted its short life, leaving behind helium, which would then be attributed to the radio-active constituents still remaining, and thus give results in excess of the truth.[1]

This new method of investigation is of great promise, but a long series of concordant observations will be required before we can feel absolute confidence in its results.

The Age of the Ocean.—We may now pass to the consideration of the well-known method of Prof. Joly. This is based on the simple equation $\frac{Na_o}{Na_r} = x$, where Na_o represents the quantity of sodium contained in the Ocean, Na_r the quantity annually discharged into it by all the rivers in the world, and x the time which has elapsed since the Ocean first came into existence.

The quantity Na_o is readily found from the volume of the Ocean and its average chemical composition. The composition has been determined with extreme accuracy, the analyses of Dittmar leaving

[1] Prof. Joly informs me of a case in which a specimen of pyromorphite was shown to have absorbed radium, without uranium, to the extent of 10 centigrams to the ton.

nothing to be desired on this point. The volume is less precisely known; it is obtained by multiplying two quantities only approximately ascertained—the estimated area and the estimated mean depth. Sir John Murray gives it as 323,800,000 cubic miles.[1] Prof. Joly, using Prof. H. Wagner's estimate of the area, arrives at 339,248,000 cubic miles[2]; Dr. F. W. Clarke gives 302,000,000[3]; and Dr. K. Karsten[4] 307,496,000. Between the highest and the lowest of these estimates there is a difference of about 10 per cent., an almost negligible quantity in an enquiry like the present. We may take 310,000,000 as sufficiently near the truth, and using this number we obtain the results given in the following table:—

TABLE I.—*Quantities of substances held in solution by the Ocean.*

Na	$13{,}982{,}000 \times 10^9$ tons	Cl	$25{,}211{,}400 \times 10^9$ tons
Mg	1,704,200 „	Br	87,000 „
Ca	545,120 „	SO_4	3,508,110 „
K	504,700 „	CO_3	93,048 „

Thus, in round numbers, the quantity of sodium present in the Ocean amounts to 14×10^{15} tons.

The next quantity to be determined (Na_r) is the annual amount of sodium carried down into the Ocean by rivers, and with this our real difficulties begin. The requisite data are scanty and imperfect. For the greater number at our disposal we are indebted to the Government of the United States, which pursues, greatly to the advantage of its people, an enlightened policy, with regard both to this and all other branches of geology. Directly we cross the Canadian frontier information begins to fail; no systematic analyses of rivers have been made in the Dominion, not even of the St. Lawrence, and such isolated analyses as exist are of comparatively little value. As to the composition and annual discharge of the Mackenzie we know absolutely nothing. It is the same when we turn to other regions under the British flag: we have no analyses of the Ganges, the Indus, or the Niger, not to mention the smaller rivers of British India, Africa, Australia, and New Zealand. When the rivers of the British Empire have been as thoroughly surveyed as those of the United States, we shall be in a better position to discuss the problem before us: in the meanwhile, we must make the best use of such information as we possess.

[1] Scottish Geogr. Mag. 1888, p. 39.

[2] J. Joly, Trans. Roy. Dub. Soc. vol. vii (1899) p. 30.

[3] 'The Data of Geochemistry' Bull. no. 330, U.S. Geol. Surv. 1908, p. 22.

[4] 'Eine Neue Berechnung der Mittleren Tiefe der Oceane' Inaug.-Diss., Kiel, 1894.

The method used by Prof. Joly in arriving at an estimate was based on the results of an investigation published by Sir John Murray.[1]

Two factors enter into the calculation, whatever method is employed: these are first the volume of the water discharged by the rivers, and next the chemical composition of this water as determined by analysis.

To find the volume of the water Sir John Murray estimated (1) the total rainfall of the globe and (2) the fraction of this which flows away in rivers. The fraction is taken as 0·222,[2] and this multiplied into the rainfall gives 6,524 cubic miles, a result which must of course be regarded as only roughly approximate.[3]

[1] Scottish Geogr. Mag. *loc. cit.*

[2] This fraction is of fundamental importance to our enquiry. Sir John Murray does not give the data on which it is based. In the few instances known to me its value is generally much higher, as will be seen from the following table:—

Rhine (Cologne)	0·518	Muskigum	0·330
Weser (Baden)	0·347	Genesee	0·352
Elbe (Geisthacht)	0·263	Croton	0·461
Oder (Küstrin)	0·255	Hudson	0·527
Vistula (Stromtutz)	0·255	Connecticut	0·511
Memel (Stromtutz)	0·339	James	0·327
Danube (Vienna)	0·526	Mississippi	0·25
Rhône (mouth)	0·878?	Rio Grande (El Paso)	0·237?
Garonne	0·532	Androscoggin	0·555
Klarelf (Sweden)	0·750	Colorado	0·190?
Fyris	0·350		

[3] The latest account of the distribution of rainfall is given by Supan (A. Supan, 'Die Verteilung des Niederschlags auf der festen Erdoberfläche' Petermann's Mitth. 1898, Ergänzungsheft No. 124). His results are plotted on a map, and I have transferred them to another map constructed upon the principle of equal areas, so that, by cutting out the regions of equal rainfall, I could approximately estimate the amount of rainfall by weighing them. In this way I obtained the following:—

Area of Land in square miles.	*Rainfall in inches.*	*Total rainfall in cubic miles.*
12,281,923	0 to 10, mean 5	969
12,823,335	10 to 20, „ 15	3,036
6,668,886	20 to 30, „ 25	5,457
6,336,712	30 to 40, „ 35	3,501
10,965,458	40 to 80, „ 60	10,390
3,191,886	80 + „ 80+	3,023+
52,268,200		26,376+

The Antarctic continent and the greater part of Greenland have been excluded

The chemical composition was obtained by taking the average of such analyses as were available at the time, but no information is given as to the details of the calculation: we do not know how the analyses were weighted, we do not even know the names of the rivers which furnished them. On the whole it would seem that of all the data on which we have to depend this is the least trustworthy. It gives 24,106 tons of sodium per cubic mile of river-water, and we thus have a total annual delivery of $24{,}106 \times 6524 = 15{,}727 \times 10^4$ tons nearly, and consequently

$$\frac{14{,}000 \times 10^{12}}{15{,}727 \times 10^4} = 90 \times 10^6 \text{ approximately,}$$

or the time which has elapsed since the first formation of the Ocean amounts to about ninety millions of years.

After a very full discussion of the various factors which might modify this result, Joly was led to assume ninety-six millions of years as the most probable estimate.

It may be worth while to probe this method [1] a little deeper, especially as regards the quantity of sodium brought down by rivers.

To obtain a completely satisfactory result, we require to know the average volume and composition of all the important rivers of the world; failing this, we might endeavour to obtain an average by a thorough study of the rivers of a single continent. Let us make the attempt, selecting North America, as likely to afford us the largest amount of information.

The data we require are (1) the average annual discharge of each river, as determined by measurements made near its mouth over a period of about forty years; and (2) the average annual composition, as determined by analyses made at the same stations and at the same times as the measurements of discharge.

As regards (1) we possess, except in the case of Canada, a number of sufficiently trustworthy averages; but, unfortunately, it is not always possible to make use of them in connexion with (2). For, though there are many rivers of which the average

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from the calculations. When these are taken into account the total land-area found by my method is 56,646,730 square miles, an excess of about 1·2 per cent. over the true area. This gives a check on the correctness of the results. It will be seen that if we take 0·25 instead of 0·222 as the fraction representing the run-off, the final result is not very different from Sir John Murray's.

[1] For an interesting criticism, see Rev. O. Fisher, Geol. Mag. dec. 4, vol. vii (1900) pp. 124 & 132.

composition has been determined by systematic observations extending over a whole year, yet these observations have not been made at stations near the mouth but at others situated up-stream, far away from it. The composition of a river at one part of its course affords no information, germane to this enquiry, as to its composition at any other part; and consequently we cannot apply the analytical results obtained at any up-stream station to the volume of water passing out to sea near the mouth, but only to that volume which passes the station where the analysis was made.

In a number of other cases we are still worse off, and must trust to isolated analyses, which, even if trustworthy, only inform us of the composition of the stream on a particular day; and this may be very different from the average.

The cases which afford the keenest disappointment to the investigator are those in which all the data are perfect except one, the analyst, for some unknown reason, having failed to separate the sodium from the potash, the two being given lumped together as alkalies.

From such material as I have been able to gather together, I have obtained the results given in the following table:—

TABLE II.

River.	*Area of Basin.*	*Discharge.*	*Sodium.*
St. Lawrence	240,000	70·591	1,480,200
Androscoggin	2,090	·652	7,277
Merrimac	2,340	·911	39,080
Croton	339	·122	1,024
Mohawk	1,306	1·289	19,010
Potomac	9,650	1·722	23,900
James	6,230	2·144	21,820
Cahaba	1,040	·395	6,139
Mississippi	1,257,545	132·355	4,764,140
Grande del Norte	38,000	·298	70,315
Pecos	?	·083	135,100
Colorado	225,049	5·746	3,262,000
Cedar	?	·144	148
Snake	17,900	1·557	242,300
Sacramento	9,300	7·613	350,950
Total	1,810,789 [1]	225·622	10,423,403

[1] The area of the basin, given in square miles, is the area of that portion of it which lies above the station where the discharge was measured: the discharge, stated in cubic miles, is the discharge at the station of observation,

By dividing the total number of tons of sodium by the total number of cubic miles, we obtain the number of tons of sodium, namely, 46,200, in one cubic mile of river-water. The number obtained from Murray's estimate is, as we have seen, 24,100; and it is upon this basis that Joly's estimate of 90 millions of years depends. By substituting the number just obtained, we arrive at 90 millions $\times \frac{24{,}100}{46{,}200} = 47$ millions of years.

The total rainfall of North America, as estimated by Murray, amounts to 561×10^{12} cubic feet or 3811 cubic miles. If the average run-off may be taken at 0·222, this gives us in whole numbers 846 cubic miles of river-water. The volume of river-water on which our result is based is 235 cubic miles, or 0·278 of the total amount. This might afford a sufficiently trustworthy average, if the rivers on which it is based were fairly distributed; but the necessary omission of the more northerly rivers, to some extent impairs its value.

The total area of the North American continent is about 9×10^6 square miles, and the area drained by the rivers that we have taken into account is a little more than 1,808,710 square miles, or about one-fifth of the total. Thus rather more than one-fourth of the river-water is derived from one-fifth of the area of the continent. The difference is in the right direction, since the greater part of the remaining area belongs to the more northerly part of the continent, where the rainfall and run-off are both less, and it includes besides extensive desert-regions.

The average composition of the northern rivers might differ from the average that we have already found. Fortunately, a single analysis has been made of one of these rivers, the Nelson, which drains a fairly large area in Northern Canada. The water of this contains near its mouth 45,850 tons of sodium to the cubic mile—a remarkably close approximation to our average.

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which in several cases is situated some distance above the mouth; in making the calculation its value was carried to the fifth decimal place: the sodium is given in tons. The analyses from which the amount of sodium was determined are given by F. W. Clarke, in the 'Data of Geochemistry': St. Lawrence p. 61 (G), Androscoggin p. 62 (C), Merrimac p. 62 (D), Croton p. 62 (H), Mohawk p. 62 (G), Potomac p. 63 (L), James p. 63 (M), Cahaba p. 63 (C), Mississippi p. 65 (G), Rio Grande del Norte p. 69 (B), Pecos p. 69 (C), Colorado p. 69 (D), Cedar p. 70 (B), Snake p. 70 (C), Sacramento p. 70 (U). The other data have been taken from the Water-Supply Papers of the U.S. Geological Survey.

A single continent might present exceptional conditions, we will therefore next turn to South America. The data at our disposal relating to the rivers of this continent are very imperfect. Our knowledge of the composition is confined to a few isolated analyses. The results calculated from these are as follows:—

TABLE III.

River.	*Area of Basin.*	*Discharge.*	*Sodium.*
Amazon[1]	2,500,000	527·951	2,475,000
La Plata...............	1,600,000	188·746	12,170,000
Uruguay...............	?	32·137	514,230
		748·834	15,159,230

The average quantity of sodium per cubic mile in this case is 21,470 tons. Using this number in connexion with Joly's estimate, we obtain 101 millions of years as the age of the Ocean.

The total rainfall of South America is 7,297 cubic miles, as estimated by Murray; and this, multiplied by 0·222, gives 1824 as the total run-off. Of this, 749 cubic miles enter into our estimate, which is based therefore on about two-fifths of the total discharge.

A study of the more important rivers of Europe affords the following results:—

TABLE IV.

River.	*Discharge.*	*Na (including NaCl).*	*Na (excluding NaCl).*
Seine, Paris	3·5207	105,100	44,060
Loire, Orleans	2·00 (?)	76,000	
Rhône, Geneva	1·9308	39,375	34,428
Elbe, Tetschen	2·4090	88,930	41,400
Danube, Vienna...............	13·8621	160,230	85,040
Klarelf, Sweden...............	1·6360	14,970	12,800
Indaself, ,, ...	·4200	35,430	2,883
Fyris, ,, ...	·0840	1,773	
Dwina, Archangel............	26·5000	1,826,000	
Rhine, Cologne	16·3923	259,300	246,470
	68·7549	2,607,108	467,081

[1] In the case of the Amazon I have used Frankland's analysis, tabulated by Clarke, *op. cit.* p. 74 (B); in the case of the La Plata, an analysis by J. J. Kyle, Clarke, p. 75 (A); and in the case of the Uruguay, an analysis also by Kyle, Clarke, p. 75 (D). In all cases the discharge is quoted from Murray.

This gives an average of 37,920 tons per cubic mile of river-water, and, taken in connexion with Joly's estimate, would lead to a period of 57 millions of years.

Combining all three results, we obtain :—

	Discharge.	*Sodium.*
North America	225·622	10,423,403
South America	748·834	16,076,230
Europe	68·757	2,607,368
	1,043·213	29,107,001

or an average of 27,900 tons of sodium to the cubic mile, and a period of $90 \times \frac{24,100}{27,900} = 78$ millions of years, approximately.

So far we have assumed that the sodium met with in the river-water has been contributed *ab ovo*, as it were: that is, we assume it to have remained locked up in the terrestrial rocks since the first consolidation of the crust down to a comparatively recent time, when it was liberated by disintegration and transferred to the waters of some running stream. The essence of this disintegration is supposed to lie in the transformation of silicates into carbonates, with the simultaneous extrication of silicic acid. The existence of argillaceous deposits, which form so large a part of the stratified crust, implies some such transformation, and the presence of silicic acid in existing rivers shows that it is still in continual progress at the present day.

As a natural inference, we should expect to find the sodium in our rivers in the state of carbonate; while, as a matter of fact, the greater part of it exists as chloride, and the remainder as sulphate. There is no difficulty in accounting for the presence of the sulphuric-acid radicle, but the chlorine is enigmatical and disquieting.

Chlorine is well known to occur in falling rain-water. The winds which agitate the sea tear off the breaking crests of the waves and sweep the spray along with them. Along the coast, so often fringed with a margin of boiling surf, this action is especially marked. The fine particles of spray are so minute that they are often carried far inland. It is indeed conceivable that under the influence of evaporation their dimensions might become so far reduced that at length nothing might remain of them but a minute residue of sea-salt, and this might fall as an impalpable snow even over desert-regions. Some observers, particularly those living near the sea-coast, have been so impressed

by this possibility as to have imagined that some inland lakes, like the Dead Sea for instance, may have received their supplies of salt from the winds.[1]

We are fortunate in possessing some very precise information on this subject. In England, according to Sir Archibald Geikie, the mean amount of chlorine present in rain-water is 2·2 parts per million. But it is to the United States that we must again turn for the most systematic investigation. The amount of chlorine in the rainfall has been determined at a large number of stations distributed over the eastern maritime provinces, between lat. 40° and 47° N. and from the coast to about 350 miles inland. The results have been plotted on the map (fig. 2, p. xcviii) by curves known as isochlors. These run approximately parallel to the coast: the outermost curve, representing 6 parts of chlorine per million of water, is rapidly succeeded by the isochlors 5, 4, 3, and 2; the spacing then becomes wider till the isochlor of 0·2 is reached. It cuts the north-western extremity of Lake Erie; beyond the Ohio the air is free from salt.[2]

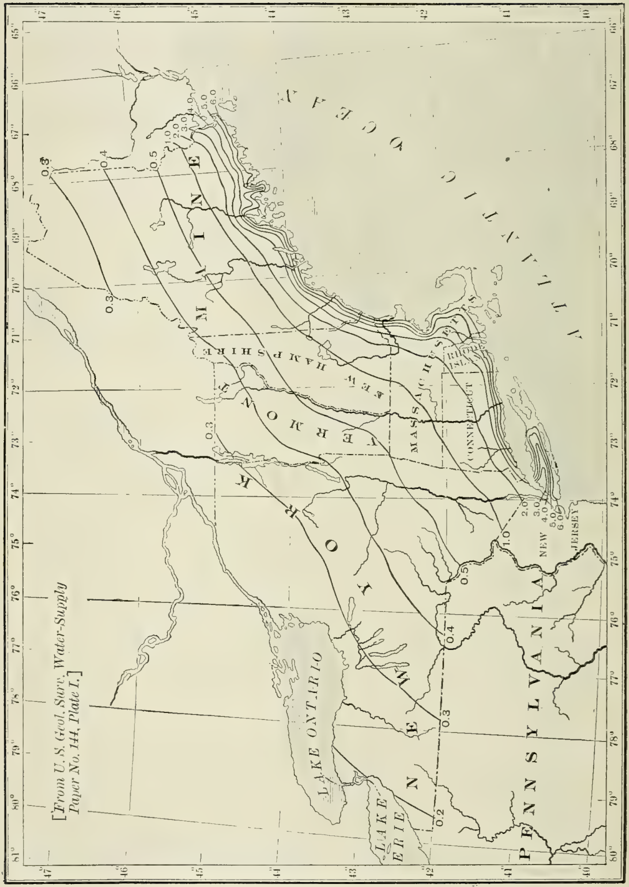
Nevertheless, as we proceed westwards beyond the Ohio, there is no falling-off in the amount of sodium-chloride contained in the river-water; on the contrary, it increases, as is particularly well shown by the western tributaries of the Mississippi. This salt does not come from the rain, and we must seek for it in the soil. Salt-bearing Trias, however, is known to extend from the eastern base of the Canadian Rockies to New Mexico, and it occurs in the Black Hills of South Dacota. These feed the western tributaries, and the Red River owes its colour to Trias marls or clays. The salt of these deposits is certainly not an immediate result of

[1] Pošepny, 'Zur Genesis der Salzablagerung &c.' SB. Wien. Ak. math.-naturw. Kl. vol. lxxvi (1877) Abth. i, p. 179. (In connexion with this, see E. Tietze, 'Zur Theorie der Entstehung der Salzsteppen, &c.' JB. k.-k. Geol. Reichsanst. Wien, vol. xxvii, 1877, p. 341; and Muntz, 'Sur la Répartition du Sel Marin suivant les Altitudes' C. R. Acad. Sci. Paris, vol. cxii, 1891, p. 447.)

W. Ackroyd, 'On the Circulation of Salt & its Bearing on Chemico-geological Problems, more especially the Age of the Earth' Chem. News, vol. lxxxiii (1901) pp. 265–268; *id.*, 'On the Circulation of Salt in its Relations to Geology' Geol. Mag. dec. 4, vol. viii (1901) pp. 445–469 & 558–559; *id.*, 'The Circulation of Salt, &c.' Proc. Yorks. Geol. & Polytech. Soc. vol. xiv (1901) pp. 401–421; and a reply by J. Joly, 'Circulation of Salt, &c.' Geol. Mag. *tom. cit.* pp. 504–506.

[2] Jackson, Water-Supply & Irrigation Paper, No. 144, U.S. Geol. Surv. 1905. The chlorine in the atmosphere did not escape the notice of Prof. Joly, who made the ample allowance of 10 per cent. for it in his estimate.

Fig. 2. (*See p. xcvii.*)



[*From U. S. Geol. Surv. Water-Supply Paper No. 144, Plate I.*]

contemporaneous disintegration; it may perhaps fairly be included in our estimates, but not until we have enquired further into its origin. As a first step, we may refer it to the waters of an ancient salt-lake now dried up. But it is not so easy to account for the origin of the salt in such a lake. In some cases, as in the massive deposits of Stassfurt, the arguments in favour of a marine origin seem conclusive. In other cases, as in the Trias of our own islands, we are accustomed to look to the waters of the inland drainage as the source. If this view be correct, as the facts seem to indicate, then the ultimate origin of the salt still remains to be discovered.

May we suppose that it is to be found in what Pošepny terms 'juvenile' water?

The rise of the Armorican mountains was accompanied, in the South-West of England, by the intrusion of great granitic masses: whether these actually gave rise to volcanic phenomena at the surface need not be discussed in this connexion; but that hot springs were fed by them with mineral matter appears to be certain. The roots of such springs, now exposed by denudation as metalliferous lodes, seam the ancient rocks of Cornwall and Devon. Saline solutions still circulate in these lodes, as in the case of Huel Clifford, near Camborne, where hot water (125° F.) was encountered at a depth of 1320 feet below sea-level, issuing at a rate of 150 gallons per minute, and charged with salts, chiefly chlorides, to the extent of about 9000 parts in one million. Similarly, at Huel Seton, in the same neighbourhood, a stream was met with at a depth of 780 feet, which was found to contain chlorides to the extent of 14,000 parts per million.[1]

During the epoch of the Trias, when these numerous lodes were overflowing with saline solutions, they may have afforded large supplies of sodium-chloride to the contemporary inland seas. The presence of copper-ores and rare vanadium-minerals in the New Red marls is suggestive in this connexion.

There is increasing evidence to show that the great kaolin-stocks of Cornwall and Devon were produced by the action of waters charged with chlorine ascending from below. They are not the result of atmospheric weathering. However deeply down they have been followed by excavations, they have never given

[1] J. A. Phillips & H. Louis, 'A Treatise on Ore-Deposits' London, 1896, pp. 201–202.

signs of coming to an end.[1] These stocks may be regarded as having been an important source of sodium-chloride.

Hot springs are probably only one of the superficial manifestations of the deep-seated juvenile waters. They may possibly infect the shallower or 'vadose' circulation with various kinds of mineral matter, including sodium-chloride.

Juvenile waters discharge directly into some of the tributaries of the Mississippi—the hot springs of the Yellowstone Park for instance, some of them, like Old Faithful, containing 367 parts of sodium per million and 439 parts of chlorine.

Prof. Suess [2] has assigned an even greater importance to juvenile waters. They are emitted, according to him, as exhalations from the heated interior of the earth, and furnish fresh supplies of saline water to the Ocean, which has thus been maintained in a state of continuous growth from the very earliest times down to the present day.

The quantity of sodium-chloride supplied by this means to the Ocean may be great, but unfortunately we have no means of estimating it. On the other hand, ancient deposits are certainly the source of a large proportion of the salt met with in existing rivers; and the practical question which presses for solution is as to what extent, if at all, this should be reckoned as an asset in calculating the annual supply of fresh sodium to the Ocean.

If the sodium of these deposits is of marine origin, it must certainly be excluded. If it is the product of an ancient system of inland drainage, it might fairly be taken into account, provided we could be sure that it was being supplied at an appropriate rate; but we have no criterion by which to judge what this rate should be. If we could base our calculation on statistics relating to the total freshwater drainage of the world, this difficulty would probably disappear; for, if at certain localities the rate of supply were above the normal, at others it would be below, and on the whole irregularities would cancel out. The region with which we have to deal is hardly large enough for this; but attention may be called to the Great Inland Basin of North America, which is cut off from all apparent communication with the Ocean, and thus intercepts a large amount of sodium. This is not sufficient,

[1] J. H. Collins, Quart. Journ. Geol. Soc. vol. lxv (1909) p. 155.

[2] Eduard Suess, 'Ueber Heisse Quellen' Verhandl. Gesellsch. Deutscher Naturforscher & Ærzte, 1902, Allgem. Theil.

however, to compensate for the rich supplies received by the western rivers of that continent.[1]

We might perhaps hope to obtain a minimum estimate of the contributions made by freshly liberated sodium to the sea, by excluding all that part of it which exists in combination as chloride, or rather so much of it as corresponds to the ratio of sodium to chlorine in existing ocean-water, that is 0·6502 of sodium to 1 of chlorine. By this procedure, however, a good deal of sodium which ought to be taken into account, such as that supplied by hot springs, would be excluded. Still, I have thought it worth while to make calcuations on this basis, with the results shown in the following table:—

TABLE V.

River.	*Sodium.*	*Silica.*
St. Lawrence	1,093,000	5,000,000
Androscoggin	3,537	25,750
Merrimac	8,187	115,760
Croton	68	1,907
Mohawk	12,285	35,300
Potomac	0	37,520
Delaware	14,913	86,800
James	16,235	89,055
Cahaba	2,990	74,350
Mississippi	1,322,550	6,094,000
Grande del Norte	33,700	19,480
Pecos	14,640	2,890
Colorado	1,832,000	502,200
Cedar	......	1,060
Snake	74,410	......
Sacramento	211,960	582,800
	4,640,475	12,668,872

The total quantity of sodium (not combined with chlorine) is 4,640,475 tons, contained in 227·659 cubic miles of river-water: this gives 20,400 tons to one cubic mile. Substituting this for

[1] On this point reference may be made to Mr. Fisher's analyses of the quarry-water contained in deep-seated Chalk and Jurassic Limestones (Analyst, August, 1901; vol. xxix, 1904, pp. 29–44). The Rev. O. Fisher (*loc. cit.*) has called attention to the mother-liquor in sedimentary rocks, which he attributes, probably with justice, to ancient sea-water. Mr. Lane does the same (A. C. Lane, 'Salt-Water in the Lake Mines' Portage Lake Mining Gazette, Houghton, Mich., separate copy, no date, 1908 ?). But it is very unlikely that this mother-liquor enters to any large extent into the composition of river-water.

24,100, the number of tons to the cubic mile used by Joly in his calculation, we obtain 106 millions of years for the age of the Ocean.

May this be regarded as a maximum, a definitely ascertained limit, which may not have been reached, but cannot possibly have been exceeded? Scarcely. Doubts may well be entertained on this point, for although no sodium known to have been derived from the sea enters into the calculation, yet some is still supplied from ancient stores, and these may possibly be in process of depletion at an exceptionally rapid rate. This is, in fact, suggested by the excessive amount of sodium contained in the rivers which drain the Pacific slope of the continent. The neglected sodium supplied by hot springs may or may not compensate for this.

On the other hand, if we now turn to South America, we perceive at once that to eliminate all the sodium existing in combination with chlorine is too drastic a proceeding, for it leaves the Amazon absolutely destitute of this constituent. This surprising result increases our mistrust of the analyses, or at least of the methods by which samples of the water were obtained for investigation. We will not on this account, however, at once abandon our present train of thought, and we will introduce the rivers of South America into our calculation; I give below the quantities of sodium, in excess of the chlorine-ratio, found in the three South American rivers already mentioned.

Table VI.

River.	*Sodium.*	*Silica.*
Amazon	......	23,982,000
Uruguay	176,900	3,848,000
La Plata	7,287,000	14,970,000
	7,463,900	42,800,000

If we combine the results obtained from the two continents, we may to some extent effect that compensation which would be complete if we were able to take into account the whole river-drainage of the world.

	Volumes.	*Sodium.*	*Silica.*
North America	227·708	4,640,475	12,668,970
South America	748·834	7,463,900	42,800,000
	976·542	12,104,375	55,468,970

The quantity of sodium in one cubic mile, found by dividing the

total quantity of sodium given in tons by the total number of cubic miles of river-water, amounts to 12,410 tons, or a little more than one half of Joly's number (24,100), and thus gives for the duration of time about twice the amount found by him, that is about 175 millions of years. Considering that the Amazon, with a volume which contributes more than half of the total quantity of river-water stated above, is not credited with any sodium at all, I think we may admit that this result approaches a superior limit.

A good deal of interest attaches to the silicic acid of the river-water. It might, indeed, provide us with a check on the sodium-estimates, were it not for two circumstances. In the first place, a large amount of this constituent is extricated from solution by organisms, and used by them in the formation of their skeletal parts. From its source to its termination, every freshwater stream is constantly being robbed of its silica by diatoms and sponges. The surveys of the freshwater planctone recently commenced may enable us in the future to make an approximate allowance for this loss; at present, all we can say is that it is very great. The second difficulty lies in the fact that we are not yet sufficiently acquainted with the nature of the reactions which take place in the weathering of silicates, and in particular, we are without data as to the amount of soluble silicic acid which is liberated on their decomposition. Nevertheless, an enquiry based on these admittedly imperfect data may not be altogether without profit. Some interesting relations are obvious on inspection of Table V. The Mississippi and the rivers of the eastern coast of North America are much richer in silica than in sodium: as a curious coincidence, the ratio in the case of the St. Lawrence and the Mississippi is very nearly the same, about 1 : 5; in the rivers of the west these relations are reversed, except in the case of the Sacramento. In the Snake river silica appears to be wholly absent. On the other hand, the Mohawk, and the Amazon (Table VI), which are devoid of sodium, except that combined with chlorine, contain a very considerable amount of silica.

The average amount of silica, reckoned as SiO_2, in the rivers of North and South America, may be calculated from Tables V & VI. It amounts to 56,830 tons per cubic mile.

Is it possible to discover how much sodium might upon a reasonable expectation have accompanied this silica, when both were set free from the parent silicates? Let us attempt to answer this question.

In his estimate of the average composition of the igneous rocks of the lithosphere, Clarke shows that the elements on which we must base our calculation are present in the following proportions:— Fe 2·64: Mg 2·44: Ca 3·42: Na 2·55: K 1·86 per cent. From these numbers we obtain the following:—

1·86 K	corresponds to	11·85 per cent. of orthoclase.	
2·55 Na	,,	30·18 per cent. of albite.	
2·98 Ca	,,	17·47 per cent. of anorthite.	
		59·50	Felspar, 59·50.
0·44 Ca	,,	1·27 per cent. lime-augite.	
2·44 Mg	,,	9·76 per cent. magnesian augite.	
2·64 Fe	,,	5·77 per cent. ferrous augite.	
		16·80	Augite, 16·80.
0·19 Fe may be reckoned as magnetite.			
		Total	75·30

The felspar and ferro-magnesian minerals are thus found to exist in the same proportions as those given elsewhere by Clarke.

The final product of the weathering of the felspar is kaolin or some closely related substance; so much is clear from the results of bulk-analyses of clay and shales. But, in the reaction which gives rise to kaolin, two molecules of silicic acid are set free for every one atom of potassium or of sodium. The decomposition of anorthite, however, is not attended by the liberation of silicic acid.

In the decomposition of the augites, one molecule of silicic acid is set free for every atom of iron, magnesium or calcium.

Thus we have:—

11·85 orthoclase sets free	5·72 SiO_2
30·58 albite ,, ,,	13·30 ,,
1·27 lime-augite ,, ,,	0·66 ,,
9·76 magnesian augite sets free	5·86 ,,
5·77 ferrous augite ,, ,,	2·62 ,,
Total	28·16

Hence it appears that 28·16 parts of silica correspond to 30·18 parts of albite or to 2·55 parts of sodium, and consequently the 56,870 tons of silica present in a cubic mile of the river-water under consideration correspond to 5,146 tons of sodium.

Substituting this for Prof. Joly's standard number, we have

$$90 \times 10^6 \times \frac{24,106}{5,146} = 421 \times 10^6,$$

and thus obtain a maximum limit of 421 millions of years, which very certainly cannot have been exceeded, and with almost equal certainty was very far from being attained.

The method by which we have been led to this result excludes all sources of sodium, except those supplied by weathering; no juvenile waters enter into the account, no salts derived from ancient deposits, and the result is obviously in excess since a great but unknown amount of the silica on which it depends has been removed from solution by organic processes, leaving a mere residuum of the original supply.

Although excessive, this result has one merit at least, it sets bounds which cannot be overstepped[1] to those extravagant speculations demanding thousands of millions of years, which have sometimes been put forward even by distinguished investigators.

Having reached this insuperable maximum, we may now search for the irreducible minimum.

An extremely interesting study of the Elbe and its tributaries has been made by J. Hanamann. He has published 120 analyses or more of the waters, and among them not the least instructive are those which show the relation between the composition of the streams and the rocks out of which they flow.[2] The results of these are as follows:—

	Granite.	*Basalt.*	*Mica-schist.*	*Phyllite.*	*Cretaceous.*
CO_3	30·49	46·85	32·14	35·94	33·01
SO_4	14·12	7·94	12·86	6·45	27·69
Cl...............	6·39	1·66	7·24	10·15	2·87
Ca	11·89	20·07	12·61	11·91	22·12
Mg	3·58	5·76	5·08	5·02	5·29
Na	10·57	6·22	10·85	11·20	3·43
K...............	5·63	3·20	4·22	4·39	2·72
SiO_2............	17·33	7·67	15·00	14·94	2·87
Fe_2O_3	...	0·63	...	...	...
Totals	100·00	100·00	100·00	100·00	100·00
Salinity, parts per million.	65	364	74	48	603

It may be observed that these waters, although remote from the sea coast, still contain a very considerable amount of chlorine; this is most marked in the case of the water flowing out of the granite,

[1] It is very difficult to 'prove' anything, and it may be objected here that the silica is a measure of the amount of disintegration but not of the sodium carried into the sea, since some of the sodium may be arrested in some unknown way and retained by the land. The *onus probandi* rests with those who raise this objection.

[2] J. Hanamann, Archiv Natur. Landesdurchforschung Böhmens, vol. ix (1894) & vol. x (1898). Cited by F. W. Clarke, *op. jam cit.* p. 79.

mica-schist and phyllite, but when the salinity is taken into account it will be found equally characteristic of those proceeding from the basalt and the Cretaceous rocks. This chlorine is certainly not derived from the rain, it is native to the soil, and yet cannot be traced to ancient desert-deposits. Evidently we have still much to learn regarding the distribution of this element, and in any case it would seem that some at least, possibly a large part, of the sodium associated with chlorine, which is included in our first table, may fairly claim to be taken into account.

In the next place, since the streams from which this water was taken are much shorter than those afforded to our study by the two Americas, it may be supposed that the silica which they contain as a result of disintegration has not been exhausted to the same extent by organic agencies. It might, therefore, afford us a hint as to the ratio which might be expected to exist between the amounts of silica and sodium present in inland waters, not far from their source in disintegrating rocks. Such a hint might prove more trustworthy than the conclusions we have drawn from theoretical reactions. Deducting the sodium supposed to be associated with chlorine, the ratios in the several analyses are as follows:—

Rock.	*Sodium.*	*Silica.*	*Rock.*	*Sodium.*	*Silica.*
Granite.........	3·24	17·33	Basalt	3·46	7·67
Mica-schist ...	6·14	15·00	Phyllite	4·60	14·93
Cretaceous ...	1·56	2·87			

Thus the water from the granite gives a ratio of $Na : SiO_2 = 6 : 1$, that from the basalt of nearly $2 : 1$. This suggests a doubt as to whether the silica yielded by the decomposition of ferro-magnesian minerals is really set free (as we have supposed) in a soluble form. In the case of biotite, which we have not considered, since it is not sufficiently abundant to greatly affect our results, the silica is left on treatment with hydrochloric acid as an insoluble residue which retains the form of the original mineral.

The average ratio, taken from the above table without properly weighting, is $3:1$. If we apply this ratio to the 56,830 tons of silica previously found, we shall obtain 18,940 as the number of tons of corresponding sodium, and 114 millions of years as the age of the Ocean.

The question of submarine supplies of river-water may next engage our attention. Prof. Joly has excluded all desert-regions from his estimates as being non-contributory. At first sight this would seem a necessary precaution, but there is much to suggest that some deserts do in fact drain into the sea, not of course by

superficial, but by underground streams. The Nile loses in volume owing to evaporation after passing Aswân, yet at the same time fresh water exists underground; and that this is not stagnant but flowing, is shown by the fact that it is inhabited by freshwater fishes, crabs, and other organisms. Below the Sahara there is a flow of underground water, directed towards the south. Several distinguished geologists in Australia consider that the subterranean water of the central desert flows out under the Ocean, and issues through its floor. Prof. David asserts that it does not discharge under the channel of the Darling River, but probably finds an outlet somewhere in the Great Australian Bight.[1] David & Pittman inform us that the porous beds which hold this water are exposed over an area of 18,000 square miles and receive a rainfall of 25 inches, a large part of which is absorbed. An absorption of 20 per cent. would furnish a supply amounting to 14·2 cubic miles, and most of this must somehow find its way to the sea. In West Australia also, according to Pittman,[2] the subterranean water finds an issue below the sea: thus at Perth, an artesian well afforded a supply of 500,000 gallons per day from a depth of 500 feet. Abundant streams escape from the foot of the Darling range, but disappear before reaching the coast only 15 miles distant to the west.

Subterranean water, as a rule, is comparatively rich in dissolved material; in South Australia it contains sodium-carbonate.

Submarine outflows of fresh water are by no means restricted to the neighbourhood of desert-regions. They will occur wherever the structure of the ground affords the necessary conditions. Instances on a small scale occur off our own shores, as on the northern coast of County Clare in Ireland, where at a place close to Ballyvaghan, as Mr. J. A. Douglas informs me, fresh water bubbles up from the beach at low tide. Shepherds bring their flocks to this spot to drink. Similar cases occur on the coast of France, as in the Département des Bouches du Rhône, where springs jet up from the bottom of the sea, one of them giving rise to a considerable current at the surface. It is asserted that the water discharged by concealed affluents into the Mediterranean, between Nice and Genoa, amounts to at least 216 cubic feet per second or 0·046 cubic mile per annum, a little more than one half of the Pecos at Pecos.

Not a single persistent stream enters the Red Sea from the surface of the land, but there are several, it is said, which escape from its floor.

[1] T. W. E. David, Proc. R. Soc. N. S. W. vol. xxvii (1893) pp. 422, 423.

[2] Annual Report, Dept. Mines & Agric. N. S. W. 1897, p. 137.

A remarkable case of a sudden outburst of fresh water into the sea in the vicinity of the south point of Florida is recorded by Raymond Thomassy as having occurred in January 1857.[1] Myriads of dead fishes are said to have been seen floating on the surface in the Straits, and in the open sea boatmen drew their drinking water as if from a well. The outflow is said to have continued for more than a month, as much water being discharged as from the Mississippi itself.[2]

Apart from the continents are the numerous volcanic islands of the Ocean,—in the Atlantic, the long series beginning with Jan Mayen, and passing through Iceland to Tristan da Cunha and the Bouvets,—in the Pacific, many scattered groups, including Fiji, Samoa, and the Hawaiian Islands. These occupy it is true only a comparatively small area; but they furnish disproportionately large supplies of sodium, owing to their favourable situation as well as to other circumstances. They are watered by an abundant rainfall, the greater part of which sinks into the porous material of the cones, and then flows outwards and downwards, often guided by the lava streams and mantles of ash and scoriæ, which are disposed as though with the special design of facilitating a quaquaversal subterranean drainage. The existence of such a drainage is well known. W. Lindgren,[3] after a careful survey of the island of Molokai, estimates the rainfall on one part of the southern slope, 54 square miles in area, as equivalent to 194 cubic feet per second: of this (in round numbers) 40 to 56 feet are lost by evaporation, 31 to 46 feet run off in streams, and 93 to 124 feet sink into the ground. This water is tapped by numerous wells sunk near the coast. On the northern side of the island, which is much steeper, the proportion of run-off is greater. On the coast in the neighbourhood of Honolulu the underground water of Hawaii itself has been reached by artesian wells, few of them more than 500 feet deep. They yield 275 millions of gallons *per diem*, or 0·1094 cubic mile *per annum*: the salinity amounts to 13 or 14 grains per gallon.[4]

The nature of the volcanic material, much of it being finely divided and in a state of glass, renders it peculiarly susceptible to chemical disintegration. Even the superficial streams of Hawaii, as shown by numerous careful analyses, contain on the average

[1] R. Thomassy, 'Essai sur l'Hydrologie' 1857.

[2] For most of the preceding instances I am indebted to Élisée Reclus, 'The Earth,' section 1. London, 1871, cap. xlii.

[3] Waldemar Lindgren, 'The Water-Resources of Molokai, Hawaiian Islands' Water-Supply & Irr. Paper No. 77, U.S. Geol. Surv. 1903.

[4] Boultbee, Proc. Roy. Soc. N. S. W. vol. xxxvii (1903) p. clxi.

100,270 tons of sodium to the cubic mile, while the underground waters must be much richer.

In the interior of the volcano, which is beyond the reach of observation, an elevated temperature must play an important part.

The composition of the water obtained at Honolulu is not stated by Mr. Boultbee; the shallower wells sunk along the southern coast of Molokai are extremely rich in sodium-chloride, and their salinity is said to increase with their distance from the centre of maximum precipitation: thus at Kawela the water contains 400 parts of salt to the gallon, at Kaunakalai 800 parts, and at Palaau as much as 1540 parts, or even more. Some of the wells in these localities were pumped for a considerable time without increasing the salinity, but it not infrequently happened that on sinking the well deeper sea-water was encountered at depths of 120 to 160 feet.

If we could argue from the estimate made for the 54 square miles on Molokai to the 6040 square miles which form the total area of the Hawaiian Islands, we should have a total run-off of 5146 seconds-feet, and a total subterranean drainage of 11,185 seconds-feet.

The average amount of sodium in the run-off of Hawaii is 24·5 parts per million, which gives a total annual discharge of 100,340 tons. If we suppose the underground water of Honolulu to have the same composition as the run-off—then, allowing for the extra salinity, this gives 39·6 parts of sodium per million, and a total annual discharge of 388,800 tons per annum; thus, by this estimate, 489,140 tons of sodium would be contributed annually to the sea by these islands. This may be compared with the amount supplied by some of the rivers of North America:—

Hawaii...............	6040 square miles	489,140 tons of sodium.
James River	6200 ,, ,,	21,820 ,, ,,
Sacramento.........	9300 ,, ,,	350,980 ,, ,,

We have no data on which to base even an approximate estimate as to the amount of sodium supplied by other volcanic regions, such as Iceland, with its numerous hot springs and geysers, Polynesia, the East and West Indies, the Philippines and many others. The area of the regions just named is 1,044,500 square miles, or only about $\frac{1}{45}$th of the entire drainage-area of the world, but $\frac{1}{7}$ of that we have been able to investigate numerically. It is evident, however, that the amount of sodium derived from this fraction might affect our estimates very appreciably.

Geologists are not perhaps completely agreed as to the precise relative importance of marine and fluviatile denudation, but there

can be no doubt that the sea exerts a powerful chemical action on many of the rocks with which it is brought into contact. Joly has himself made experiments,[1] with a view to obtaining light on this question. On the coast of Howth, near Dublin, I have been especially impressed by the complete decomposition suffered by the numerous dykes of diabase which are exposed along the cliffs to the disintegrating effects of sea-water. Many of them have entirely lost their original character, and now consist of soft porous clay.

Prof. Joly has attributed about 3 to 6 per cent. of the total supply of sodium to marine action, an allowance which seems generous when it is considered that the total area of the tide-swept region is to that watered by the rain as 1 : 700 only. But, on the other hand, the action of the sea is not confined to the selvage between tides, it extends far deeper into the land: how far, it is at present impossible to say. We have already referred to the results of boring on Molokai, where sea-water was encountered at depths of from 120 to 160 feet at several points along the coast. How far inland these wells were situated is not stated, but their sites are in several cases as much as 50 feet above sea-level.

Observations made on Funafuti showed that the upper portion of this island is freely accessible to the sea. The rise and fall of the tide is accompanied by a subterranean inflow and outflow of sea-water, and a corresponding submersion and emersion of the ground, which occurs in the very middle of several of the islets. This moving water acts as a powerful solvent on the limestone-rocks. In a bore-hole put down on the seaward margin of the storm-beach the ebb and flow of the tide produced its full effect down to a depth of 46 feet.

A certain amount of sodium-bearing material is contributed directly to the sea by volcanos. Vast masses of floating pumice are sometimes met with far from land, and volcanic ash is widely distributed by the winds. The red clay of the Ocean so widely disseminated through abyssal deposits bears testimony to the disintegration which this experiences in the sea.

The amount of sodium derived from this source is probably too small to seriously affect our estimates, but volcanic activity as a whole must play a very important part: we can observe its superficial manifestations in the escape of acid gases and the emission of juvenile waters, and at times denudation exposes some of its deeper-

[1] J. Joly, 'Expériences sur la Dénudation par Dissolution dans l'Eau Douce & dans l'Eau de Mer' Compt. rendu VIIIème Congrès Géol. Internat. Paris 1900 (Paris 1901).

seated effects, such as the kaolinization of granite or the formation of mineral lodes; but over and above these are many secret processes leading to the extrication of sodium, the nature of which must always remain a matter for inference or speculation. This is especially true in the case of Oceanic volcanos: within the heated interior of these large quantities of sodium-bearing salts may be liberated, and subsequently conveyed by one means or another into the sea, without affording any outward signs of the fact. The effect of these processes, however great, must, of course, remain for all time beyond the reach of numerical estimates. Neither can the contributions made by subterranean streams and submarine action in general be expressed in figures: the irreducible minimum eludes us, and all that we can assert is that the various estimates of the age of the Ocean previously obtained are in excess to an undetermined amount. These estimates are as follows:—

(1) Judged from the total amount of sodium contained in some of the rivers of North America	47	millions	of years.
(2) Do. do. do. of South America ...	101	,,	,,
(3) Do. do. do. of Europe	57	,,	,,
(4) From estimates 1, 2, 3 combined	77	,,	,,
(5) From the total amount of sodium (exclusive of that combined with chlorine) in some of the rivers of North and South America	175	,,	,,
(6) From the silicic acid of some of the rivers of North and South America	421	,,	,,

The last of these estimates is unquestionably too high: it is an impossible maximum, rather illustrating the power of organisms to remove silica from solution than affording a measure of geological time.

The last but one again is almost certainly too high. It is difficult to be quite certain on this point, because some of the sodium on which the estimate depends is supplied from ancient deposits. On the other hand, there can be no question that some of the sodium which was excluded from consideration should come into the account, for some sodium-chloride is supplied by juvenile waters; further, no allowance has been made for a number of factors which, though important, cannot be estimated numerically.

The fourth estimate is probably too low, some of the sodium on which it depends having been derived from organic contamination and rain-water; possibly that supplied by marine action and volcanos is sufficient to compensate for this; on this point we have no certain information.

On a review of all the facts, the most probable estimate of the age of the Ocean would appear to lie between 80 and 150 millions of years.

We may now pass from the age of the Ocean to the age of the sedimentary rocks.

I have previously given on another occasion a table showing the maximum thickness of each of the stratigraphical systems ; I am now able to amend it, thanks to additional information afforded by Chamberlin & Salisbury[1] in respect to some of these systems chiefly as developed in the United States.

	A.D. 1900.	*A.D. 1909.*	
	Feet.	*Feet.*	
Recent and Pleistocene	4000	4000	
Pliocene	5000	13000	
Miocene	9000	14000	
Oligocene	12000	12000	
Eocene	12000	20000	
		———	63,800
Upper Cretaceous	14000	24000	
Lower do.		20000	
Jurassic	8000	8000	
Trias	13000	17000	
		———	69,000
Permian	12000	12000	
Carboniferous	24000	29000	
Devonian	22000	22000	
		———	63,000
Silurian	15000	15000	
Ordovician	17000	17000	
Cambrian	16000	26000	
		———	58,000
Keweenawan	50000 (?)	50000 (?)	
Animikian	14000	14000	
Huronian	18000	18000	
		———	82,000
Archæan	?	?	
		Total	335,800 feet.

On comparing the two columns it will be seen that the chief increase in thickness is confined to the Cambrian, the Cretaceous, and some of the Tertiary systems : the thickness of the Jurassic, although very disproportionate to the importance of that system, remains unchanged. It is to be hoped that some future discovery may diminish this anomaly.

The total thickness amounts to 335,800 feet, and if this accumulated at the rate of one foot in a century, the duration of stratigraphical time would amount to more than thirty-three and a half

[1] T. C. Chamberlin & R. D. Salisbury, 'Geology' London, 1906.

millions of years, or in round numbers to thirty-four millions. This is very much less than the minimum estimate found for the age of the Ocean, indeed about one-half; and, since the deposition of sediments must have commenced with the birth of the Ocean, we are at once confronted with a discrepancy which demands our serious attention. It is true that we possess no definite information regarding the rate at which the ancient sediments were accumulated, but it seems extremely unlikely that in those places where they attain their maximum thickness the rate can have greatly exceeded that which we have assumed.

Something, no doubt, will be set down to our ignorance of the early history of the stratified rocks—the Archæan still remains shrouded in mystery. Ancient systems may have existed which have since disappeared, either wholly or in part, by absorption into the underlying crust. Sederholm believes that he has discovered a whole series of such systems partly destroyed and completely transformed by invading igneous floods, these he names the Ladogian, Bottnian, Upper and Lower Kalevian, Jatulian, and Jotnian, and adds that each is separated from its neighbour by an unconformity. The great Schist Series of North America presents us with another system, or set of systems, arrested midway in its progress towards destruction.

Palæontologists have repeatedly suggested that at least as much time must have elapsed before the Cambrian Period as after it, and a review of the earliest-known fauna might lead us to regard this estimate as not unreasonable. If we represent such a period by feet of sediment, then the pre-Cambrian systems should have originally possessed a thickness of 254,000 feet, and the total duration of stratigraphical time would become fifty-one millions of years. But even this is less than our fourth, and lowest probable, estimate of the age of the Ocean.

One other source of error may exist. Gaps, not represented by sediment, may occur in the series. The significance of unconformities has never been more fully appreciated than it was in the middle of last century, when Ramsay with great insistence called attention to the vast lapse of time which an unconformity involves. In his masterly contribution to the first volume of the memoirs of the Geological Survey, published in 1846, he showed how some 20,000 to 30,000 feet of Palæozoic sediments had been folded up and denuded away before the deposition of the New Red Sandstone. His conclusions, received with incredulity at the time, have since been relegated to the obvious.

Subsequent discoveries, made from time to time in various parts of the world, have seemed to show that unconformities however great and extensive are by no means universal, and that in certain localities especially favoured they may be bridged by a continuous series of passage-beds. At the same time, it was found that such passage-beds are not, as Ramsay's explanations had led us to expect, of any great thickness; indeed, more often than not, their thickness is inconsiderable. This fact was hard to reconcile with the admitted course of events involved in an unconformity, indeed no formal reconciliation seems at any time to have been attempted: on the other hand, a suspicion seems to have arisen, felt rather than expressed, that the importance of unconformities might have been exaggerated. It must have been a sub-conscious mistrust of this kind that led me to suppose, when first discussing the question of stratigraphical time, that unconformities might be disregarded, if only we assigned to every system its maximum thickness.

It is plain that this is not the case. With increasing knowledge we are returning to Ramsay's views, and unconformities are re-assuming their former importance. Let us restrict our attention for a moment to the great break which occurs almost all over the world at or about the close of Carboniferous times. This seemed to be bridged over in India. Without referring to the Salt Range, where the facts are still in dispute,[1] let us pass to the section at Spiti, where the Permian succeeds the Carboniferous apparently with perfect conformity, nothing but the conglomeratic character of the base of the Permian remaining to remind us of the marked discordance which occurs elsewhere. If, starting from Spiti, we proceed towards the south-east, the Permian is found to pass in succession over the upturned and denuded edges of the older Palæozoic systems, one after the other, until at length it rests directly on the Ordovician.[2] Nothing, therefore, could be more deceptive than the so-called 'conformity' at Spiti, where the basal beds of the Permian are said actually to pass down into the highest beds of the Upper Carboniferous.[3] The interval of time separating the two systems is probably no less at Spiti than it is elsewhere; and yet, save for the conglomerate, there is nothing to indicate it. The question will naturally arise whether the continuity of an apparently unbroken succession is always as real as it appears.

[1] E. Koken, 'Indisches Perm & die Permische Eiszeit' N. Jahrbuch Festband (1907) pp. 446–546.

[2] H. H. Hayden, 'The Geology of Spiti' Mem. Geol. Surv. India, vol. xxxvi, pt. i (1904) p. 52.

[3] *Id. ibid.* p. 46.

In our own islands the unconformity in question is extreme, the Armorican chain had been folded up and a great part of it levelled to the sea before the deposition of the Permian : the events described by Ramsay in South Wales[1] belong to this interval, and the great folds of northern England, which rose like a 'parma' in front of the Armorican chain, were also completely destroyed before the Lower Permian age. Thus the red marls and sands of this system rest on the Carboniferous Limestone, just north of the locality where the Carboniferous System attains its greatest thickness in these islands, no less than 10,000 or 20,000 feet of Coal-Measures, Millstone Grit, and Lower Carboniferous rocks having been folded up and removed in pre-Permian times.

On the opposite side of the Pennine chain the Magnesian Limestone rests on the Carboniferous Limestone over the region extending from Richmond to Darlington ; but here the thickness of the underlying series is less, and the denudation did not amount to more than 5000 or 6000 feet.

The extent to which the Armorican chain and its outlying ranges suffered from denudation, prior to the deposition of the Permian, is comparable to that which has affected the Alps and the Himálaya of our own time, and we can scarcely doubt that the interval of time which separates the Permian from the Carboniferous is as great as, if not greater than, that which has elapsed since the Alpine foldings of the Miocene Epoch. If expressed in terms of sediment, it might amount to 30,000 or 40,000 feet.

In our islands there seem to be at least three other unconformities of the first magnitude, (1) that associated with the Caledonian movements, (2) another immediately antecedent to the Cambrian, and a third to the Torridonian. If we include the pre-Huronian and pre-Animikian unconformities of North America, we raise the total to six, and if we include those recorded by Sederholm to nine.

Taking six as the probable number of great unconformities, and regarding them as of equal value, their duration would be represented by 18 to 24 thousand feet of sediment, the equivalent of 18 to 24 millions of years. This, added to the 51 millions previously found, would give a total of 69 to 75 millions.

There are many minor unconformities related to regressions and transgressions of the sea, as well as other interruptions in the deposition of sediment which must represent a lapse of stratigraphically unrecorded time. These are difficult to evaluate: to obtain a round number we might assign 5 millions of years

1 Mem. Geol. Surv. vol. i (1846).

to them and raise the final total to 80 millions of years. This we may divide into two moieties or æons, one pre-Cambrian—the Protæon, the other post-Cambrian—the Hysteræon; and we may regard one foot of sediment in a continuous series as roughly representing a lapse of one hundred years. This one foot in a century is certainly only a more or less plausible guess, yet it is not likely to be in excess of the truth, as regards the time, which most geologists will, I think, be disposed rather to increase than diminish.

The absence or rarity of fossils in the Protæonic sediments is still a subject of speculation, especially among those geologists who are most familiar with the Keweenawan System or its equivalents. Some of these are of such promising appearance that the observer, when introduced to them for the first time, applies his hammer in the confident expectation of a rich booty, and on reluctantly abandoning the search remains still unconvinced that the fossils are not there. A few stray traces of organisms have indeed rewarded the patience of investigators from time to time, especially in the Belt terrane of western North America. An excellent account of all that have been discovered is given by Walcott.[1] *Aspidella* is plainly organic; and so, very probably, is *Beltina*, but few geologists will, I imagine, agree in assigning it to the Merostomata without far more convincing evidence than has yet been adduced.

Dr. Daly[2] attributes the absence of calcareous fossils to a supposed limeless or rather putrid Ocean. A comparison is made with the Black Sea, where, however, the conditions are very different from those which prevail in the open Ocean. The ancestors of the Cambrian fauna must have inhabited the earth during the greater part of the Protæon, and we have no reason to suppose that their evolution was accomplished in an unwholesome environment.

The quantity of carbonate of lime in the existing Ocean is remarkably small, owing to its constant removal from solution by organisms. Rivers would contribute all that it contains in about five millions of years, that is, during the first eighth of the Protæon. The presence of thick-valved Unios in ordinary river-water shows that neither the absence of sodium-chloride nor

[1] C. D. Walcott, 'Pre-Cambrian Fossiliferous Formations' Bull. Geol. Soc. Am. vol. x (1899) pp. 199–244.

[2] R. A. Daly, 'The Limeless Ocean of Pre-Cambrian Time' Am. Journ. Sci. ser. 4, vol. xxiii (1907) pp. 93–115.

poverty in calcium-salt is a factor of the first importance in this question.

The absence of calcareous skeletons from the older rocks is, after all, not inconsistent with what might be expected from the general course of organic evolution. So far as the ontogeny is a recapitulation of the phylogeny, so far it preserves for us the successive adult states of the past. Successive adult states correspond to existing larval stages, and larvæ are either devoid of a skeleton or, if they possess one, it is too minute for preservation. Nowhere, even in sediments where the most delicate adult organisms have left their trace, has the larval skeleton of an Echinoderm hitherto been observed.[1] Yet what myriads upon myriads of these young forms have continuously inhabited the Ocean since the Cambrian time!

Hard parts develop not only for support but for defence also, and it was possibly as a defence against predaceous organisms that Brachiopods and Lamellibranchs first became possessed of a shell. Predaceous animals do not appear, however, to have been very common in the earlier Cambrian times. If we were to attempt to classify the animal kingdom by function, one of the most fundamental divisions would be into forms which feed by driving food-laden water through their alimentary canal, strainers of an 'animated soup' as it were—Ethmophagites, and those which ingest their food in a more wholesale manner—Thrombophagites. Nearly all the Cambrian animals were ethmophagous, even the lowly Trilobites may be assigned to this division: for, as Mr. W. K. Spencer has pointed out to me, these creatures probably swam upon their backs and drove food into their mouth by movements of the appendages, very much after the fashion of an *Apus*. The nature of the worms, which were apparently the dominant organisms of the time, is not sufficiently known to enable us to pronounce on their habits. The earliest Annelid teeth described by Dr. Hinde are found in the Chazy Limestone of the Ordovician System.[2] All the great sub-kingdoms of the Invertebrata are represented in the Lower Cambrian strata, but in every case by extremely primitive forms.

[1] In an earlier discussion of this subject I omitted to refer to W. K. Brooks (Journ. Geol. Chicago, vol. ii, 1894, p. 455), who had previously expressed similar ideas. The argument occurred to me quite independently, immediately after the publication of my paper on *Pucksia*, Proc. Roy. Dublin Soc. vol. viii, p. 297, read Dec. 19th, 1894. This must be my apology for unwittingly overlooking this very important contribution.

[2] G. J. Hinde, 'On Annelid-Jaws from the Cambro-Silurian, &c.' Quart. Journ. Geol. Soc. vol. xxxv (1879) pp. 351–69.

The most direct evidence as to the general course of evolution in the organic world is afforded by fossils, and enboldened by this some geologists have proceeded to pronounce judgement on a question which, some may think, lies altogether outside the range of our enquiries. This question is the controversy of controversies, popularly symbolized by the opposing doctrines of Lamarck and Darwin. The fundamental problem which underlies the whole study of evolution is without doubt that of variation; yet how slight is our knowledge, or rather how dense is our ignorance concerning this question! We know nothing as to its causation and very little as to its laws; and, as regards its efficiency in the production of species, we cannot assert positively whether it is continuous or discontinuous or both: doubts may even be entertained, as to how far it is determinate or indeterminate.[1] Geology can scarcely be expected to answer these questions; but there are others, directly related, to which she alone possesses the key.

The question of continuity or discontinuity is not, however, one of these. It is true that some groups of organisms, such as Brachiopods and Ammonites, seem to afford, in certain cases, evidence of continuous variation: on the other hand, instances are known, which superficially considered might be claimed as evidence of discontinuous variation or saltation; but these are really ambiguous, since the imperfection of the record affords an alternative explanation. This imperfection of the record is not merely a phrase invented by Darwin. Its existence is unfortunately only too real. Numerous, indeed, are the breaches in the continuity of ancentral series; Gaskell[2] and Steinmann[3] would bridge them over by methods which it is for zoologists to consider; the geologist will attribute them to imperfections in the record.

The subject on which geology can speak with authority concerns the relative rate of change by which organic transformation has been effected. Some organisms maintain their characters with such persistence throughout long periods of recorded time that they may fairly be distinguished as stable; others pass from one

[1] On this and related questions light may be expected from the important investigations now being conducted by Prof. Bateson and his school.

[2] Gaskell, 'The Origin of the Vertebrates' London, 1908. It is impossible to refuse a tribute of admiration to this remarkable work. Whatever difference of opinion may exist on the general question, there can be none as to the value of the observations or the importance of the arguments which the Author marshals in support of his views.

[3] G. Steinmann, 'Die geologischen Grundlagen der Abstammungslehre' Leipzig, 1908 (284 pp.).

stage of evolution to another with such rapidity that they may be equally distinguished as labile. But the labile stems do not continuously develop at a steady rate: there are intervals in their history, often prolonged, when they seem to pass into a resting stage and their variability becomes latent for a while. Such apparently was the case with the Mammalia during a great part of the Mesozoic Era.

The cases of rapid change are the most interesting, and as an illustration of the value of even a rough chronologic scale we may conveniently consider one or two instances in this connexion, commencing with the ancestry of the horse, which still remains the classic example of its kind, thanks to the investigations of American palæontologists, particularly Osborne and Gidley.[1]

Gidley, basing his observations on over a thousand specimens preserved in the American Museum of Natural History, enumerates some 60 species and a large number of genera; many of these do not lie in the direct line of descent, and of those that do the series is interrupted by two well-marked gaps, one between the Hyracotheriinæ and the Anchitheriinæ, the other between the Anchitheriinæ and the Protohippinæ. The series is not, however, so incomplete as to justify Depéret's assertion that 'the supposed pedigree of the Equidæ is a deceptive illusion'.[2] The species which lie more or less in the direct line, extend from the opening days of the Eocene to the middle of the Pliocene, or through a period, according to our scale, of about five or six millions of years. The horizons on which remains of the Equidæ have been found number, I suppose, some nine or twelve; between them lie intervals, some half a million of years in average duration, which represent absolute blanks in our knowledge. The Assyrian and Egyptian civilizations begin some ten thousand years remote from us, a period difficult enough to conceive: the successive stages by which we reconstruct the genealogy of the horse are separated from each other by intervals fifty times as great. We may look at it in another way: probably five years would be a fair estimate of the duration of one generation of horses, if so, then a million generations intervene between the latest species of horse and the *Eohippus* of the early Eocene times. Our knowledge of these generations is restricted to groups of ten or a dozen, perhaps a hundred, taken at random, as it were, from each successive hundred thousand. 'The argument of the insufficiency of palæontological documents' may be

[1] J. W. Gidley, 'Revision of the Miocene & Pliocene Equidæ of North America' Bull. Am. Mus. Nat. Hist. vol. xxiii (1907) p. 865.

[2] C. Depéret, 'Les Transformations du Monde Animal' Paris, 1907, p. 107.

'eternal,' but it is not 'rather worn out.'[1] The more intimate and complete our knowledge of the facts, the more deeply are we impressed with the imperfection of the record, and those who would pronounce on the question of continuous or saltatory transformation on such evidence as that just presented may be assumed to underestimate the duration of the unrecorded intervals in the genealogy.

The stages of evolution in the horse, as in other organisms, are marked by changes in relative size of the different parts of the skeleton, as well as by an increase in size of the whole. The latter, or the phylogenetic growth, affords larger quantities for measurement than the relative change of the parts, and is thus the more convenient to consider in relation to time. The facts are excellently summarized by Lull,[2] who gives the dimensions of the leading forms of Equidæ in the direct line of descent as follows:—

Eohippus	11 inches,	Wind River Eocene.
Protorohippus............	14 ,,	Wind River Eocene.
Orohippus	16 ,,	Bridger Eocene.
Mesohippus...............	18 ,,	Oligocene White River.
Miohippus	24 ,,	John Day, on the border-line between Oligocene and Miocene.
Protohippus	36 ,,	Loup Fork.
Pliohippus	48 ,,	Loup Fork, extends into Pliocene.
Equus	64 ,,	Pliocene to recent.

Thus the total increase in height in passing from *Eohippus* to *Equus* is $64-11=53$ inches; that is about 10 inches per million years. No doubt the course of evolution was not uniform, but it was sufficiently so for the purpose of our illustration. If it proceeded continuously then each succeeding generation would be taller than the immediately preceding by 0·00005 inch; if by a saltation, occurring on the average every 1000 generations, this quantity would become 0·05 inch, but the smallest increase which we could definitely ascertain by ordinary anatomical measurements would be about 0·1 inch, and this would be brought about in 2000 generations or in a period, roughly speaking, of about 10,000 years.

This example gives us some idea of the relative magnitudes with which we have to deal; it could be rendered much more effective if it were not for a lamentable deficiency of the requisite data: we look to time and the genius of our American colleagues to render our quantitative knowledge in this direction more exact.

No doubt, instances occur in which the rate of evolution among

[1] C. Depéret, 'The Transformations of the Animal World' (authorized English translation) London, 1909, p. 274.

[2] R. S. Lull, Am. Journ. Sci. ser. 4, vol. xxiii (1907) pp. 161–82.

the Mammalia has been greater than in the case of the horse. The human family, which seems to be of surprisingly recent origin, may be one of these, at least as regards the phylogenetic growth of the brain. The earliest human skulls known to us are those of the Neandertal race, with a capacity of about 1250 cubic centimetres.[1] This was the volume of the human brain, so far as is known, during the Mousterian age; in the Magdalenian it had become 1550 c.c., an increase of 300 c.c. which occurred during the interval represented by the Upper Palæolithic deposits. At present we have no means of estimating, even approximately, the value of this interval in years. For the sake of illustration we will suppose it to be 30,000 years, or three times the interval which separates us from the early civilization of Egypt. In the case of the horse we made use of linear measurements and, to be consistent, we will do so now. It will be sufficient for our purpose, if we regard the skull as a cubical box: with a capacity of 1250 c.c., this would measure internally 10·772 cms. along the edge; with a capacity of 1550 c.c., it would measure 11·573 cms., a difference of 8 mms., and this measures the increase which would be effected in the course say of 30,000 years. The rate of change is 0·024 mm. per century, or 0·008 mm. per generation of 30 years, an almost inappreciable quantity which would certainly have escaped the attention of contemporary observers.

But the palæontological record reveals only few traces of the successive stages of human evolution; we have, it is true, the intermediate horizon of the Solutrian, and corresponding skulls possibly of 1450 c.c. capacity; but there are none of those nicely graduated examples such as we should expect if the record were more complete, or if a continuous evolution had proceeded within the European area. The theatre of change was probably situated

[[1] Since correcting the proofs of the Address I have examined, under the guidance of Prof. Marcellin Boule, the Neandertal skull lately discovered at La Chapelle aux Saints. Its general appearance suggests a large volume, and Prof. Boule informed me that according to his measurements its capacity is 1600 c.c. It is the occipital region which appears to be the most developed, and the frontal lobes may be disproportionately small. A cast of the interior which Prof. Boule proposes to obtain will afford more definite information on this and related points. After seeing this skull, I should have liked to delete all that appears here relating to the evolution of Man, and am only restrained by a feeling of fairness. It may stand to point a moral.—*W. J. S., May 12th, 1909.*]

elsewhere, and the crania in our caves are the relics of successive waves of migratory invasion. The races they represent are probably the final terms of distinct evolutional series: they were comparatively stable products, and their descendants, now represented by the Australians, Bushmen, and Eskimos, retain to a large extent the cranial characteristics, and especially the cranial capacity, which they possessed when they occupied a large part of the continent of Europe. Whatever other changes the human brain may have undergone since the close of Palæolithic times, it has certainly not increased in volume.

A consideration of the rapid transformation of the Equidæ and Man, in such striking contrast to the almost complete fixity of type in *Lingula* and *Discina*, suggests a question as to the origin of the difference. What is it that induces in some of the descendants of a particular form a stable and in others a labile state? If changes in the environment afford the necessary stimulus, how is it that similar organisms respond so differently to this stimulus? The answer to this question no doubt depends on the value of the qualification 'similar'; what Leibniz assumed with regard to his individuals is true also for organisms—no two are absolutely alike, and our difficulties often arise from the use of the same word to include different things: but this is only a restatement of the fact of variation.

It will be observed that in both the instances we have just considered, the known facts provide ample time for a chronologically slow and continuous evolution of what appear to be rapidly changing organisms; but it is doubtful whether this conclusion could be still maintained if we assumed that the variations they sum up were absolutely indeterminate; what seems rather to be suggested is a succession of similar variations added one to another in a linear series. If this should prove to be the case, the next word on this subject might be expected neither from the zoologist nor the geologist, but from the student of what is known as Psychophysics. Samuel Butler's suggestive book on 'Life and Habit' may possibly prove an adumbration of a new and wide-reaching explanation of the origin of species, embracing all that is true in the great work of Darwin and of his brilliant precursor Lamarck.

February 24th, 1909.

Prof. W. J. SOLLAS, LL.D., Sc.D., F.R.S., President, in the Chair.

Thomas Clifford Fitzwilliam Hall, Geological Survey, 28 Jermyn Street, S.W., & 21 Oakley Crescent, Chelsea, S.W., was elected a Fellow of the Society.

The List of Donations to the Library was read.

The following communications were read :—

1. 'Palæolithic Implements, etc. from Hackpen Hill, Winterbourne Bassett, and Knowle-Farm Pit (Wiltshire).' By the Rev. Henry George Ommanney Kendall, M.A. (Communicated by W. Whitaker, B.A., F.R.S., F.G.S.)

2. 'On the Karroo System in Northern Rhodesia, and its Relation to the General Geology.' By Arthur John Charles Molyneux, F.G.S.

3. 'Plant-containing Nodules from Japan, considered structurally in their Relation to the "Coal-Balls" and "Roof-Nodules" of the European Carboniferous.' By Marie C. Stopes, D.Sc., Ph.D., F.L.S. (Communicated by Prof. E. J. Garwood, M.A., Sec.G.S.)

The following specimens, maps, etc. were exhibited :—

Palæolithic implements from Wiltshire, exhibited in illustration of the Rev. H. G. O. Kendall's paper.

Rock-specimens, photographs, and lantern-slides, exhibited by A. J. C. Molyneux, F.G.S., in illustration of his paper.

Carte géologique du Massif de la Dent Blanche, par E. Argand, $\frac{1}{50,000}$, 1908; Geologische Karte des Blauenberges südlich Basel, von E. Greppin, 1908; and Geologische Karte der Umgebung von Aarau, von F. Mühlberg, $\frac{1}{25,000}$, 1908. Presented by the Geological Commission of Switzerland.

March 10th, 1909.

Prof. W. J. SOLLAS, LL.D., Sc.D., F.R.S., President, in the Chair.

The Rev. Robert Stephen Edwards, M.A. Oxon., Westcote Barton Rectory, Oxford; Henry Fidler, M.Inst.C.E., Basildon, St. John's Road, Sandown (Isle of Wight); Cecil Henry Roberts,

Assoc. M.Inst.C.E., Corporation Waterworks Engineer, 33 & 35 French Street, Southampton; and Stanley Smith, B.Sc., Brandon House, Haughton-le-Skerne, near Darlington, were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. 'Some Notes on the Neighbourhood of the Victoria Falls (Rhodesia).' By Thomas Codrington, M.Inst.C.E., F.G.S.

2. 'A Contribution to the Petrography of the New Red Sandstone in the West of England.' By Herbert Henry Thomas, M.A., B.Sc., F.G.S.

The following specimens, photographs, slides, etc. were exhibited:—

Rock-specimens and photographs, exhibited by T. Codrington, M.Inst.C.E., F.G.S., in illustration of his paper.

Microscope-slides and lantern-slides, exhibited by H. H. Thomas, M.A., B.Sc., F.G.S., in illustration of his paper.

Twelve coloured lantern-slides of microscopic sections of rocks and minerals, prepared by the Lumière process, by Miss M. K. Heslop, M.Sc., and exhibited by Prof. G. A. Lebour, M.A., D.Sc., F.G.S.

Geological Survey of Scotland, 6-inch map: Edinburghshire, Linlithgowshire, etc. (Solid and Drift), twenty-four sheets. Presented by the Director of H.M. Geological Survey.

March 24th, 1909.

Prof. W. J. Sollas, LL.D., Sc.D., F.R.S., President, in the Chair.

Ernest Clayton Andrews, New South Wales Geological Survey, Sydney (N.S.W.); S. S. Dornan, B.A., P.O. Box 510, Bulawayo (Rhodesia); John Carr Gordon, 16 Windermere Road, Ealing, W.; and William Macdonald, B.Sc., M.S.Agr., Ph.D., F.R.S.E., Department of Agriculture, Pretoria (Transvaal Colony), were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communication was read:—

'Glacial Erosion in North Wales.' By Prof. William Morris Davis, For.Corr.G.S.

5. *On* LABRADORITE-NORITE *with* PORPHYRITIC LABRADORITE-CRYSTALS: *a* CONTRIBUTION *to the* STUDY *of the* 'GABBROIDAL EUTECTIC.' By Prof. JOHAN H. L. VOGT, F.M.G.S. (Read January 13th, 1909.)

THE object of this paper is to contribute to the investigation, on a physico-chemical basis, of the sequence of crystallization in the gabbroidal eruptives.

The Lofoten and Vesteraal Islands on the northern coast of Norway (lat. 67° 50′ to 69° N.) constitute, as is well known, a petrographical province with a very considerable number of eruptives, among which orthoclase-plagioclase-rocks, especially monzonite and banatite, are the most frequent.

On one of the islands, Flakstadö, there is an area of labradorite-rock[1] comparatively poor in ferromagnesian silicates and magnetite, besides labradorite-norite with somewhat larger quantities of the same. Under the name 'labradorite-norite' is denoted a rock which lies chemically and mineralogically on the boundary between labradorite-rock and norite.

The field-exposure of the labradorite-rock with the labradorite-norite has a length of 16½ kilometres, a breadth averaging from 2½ to 3½ kilometres, and an area of about 50 square kilometres. To this must be added its continuation under the sea. At the northern margin, towards the Archæan in the neighbourhood of Napp Farm on Flakstadö, the labradorite-norite occurs with a porphyritic development, that is, with phenocrysts of labradorite-felspar, often of remarkably large dimensions. We will now examine this latter rock more closely.

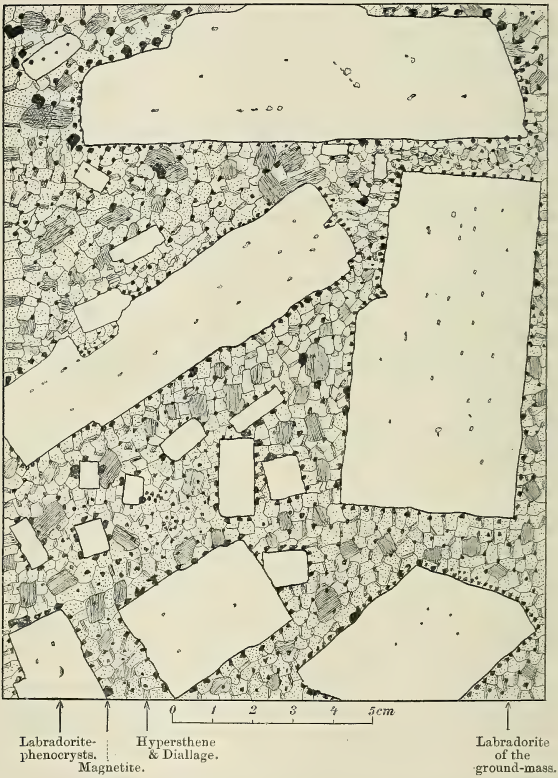
The porphyritic labradorite-norite of Napp, like most of the rocks belonging to the eruptive province in question, generally shows little or no sign of pressure. It is in most places coarsely crystalline, with labradorite-phenocrysts measuring as much as 15 or 18 centimetres in length and from 6 to 8 in breadth. It has a hypidiomorphic ground-mass of relatively coarse grain. Occasionally, however, the rock is more finely-grained, both as regards ground-mass and labradorite-phenocrysts, which are here only from 2 to 3 centimetres long.

An example of the ordinary coarse-grained rock is shown in fig. 1 (p. 82), which illustrates part of the cut and polished surface of a large block.[2] The minerals which occur therein are plagioclase (labradorite): namely, on the one hand, the plagioclase-phenocrysts, and on the other, the plagioclase (somewhat richer in albite) of the ground-mass; hypersthene and diallage, with quite a small

[1] In it basic segregations are found, on the one hand of titanic iron-ores (titanomagnetite-diallagite and titanomagnetite-spinellite), and on the other hand of peridotites, occasionally also amphibolite: see J. H. L. Vogt, Zeitschr. f. prakt. Geol. vol. viii (1900) p. 233.

[2] I was unable to obtain any usefully illustrative photograph from the surface, and so I have preferred to make a freehand drawing.

Fig. 1.—*Polished section of the coarse-grained porphyritic labradorite-norite of Napp Farm, Flakstadö. (Two-thirds of the natural size.)*



[The large porphyritic crystals are labradorite; the black patches represent magnetite; the striated patches are hypersthene and diallage and the dotted areas represent the labradorite of the ground-mass.]

quantity of secondary hornblende; magnetite (titanomagnetite); a little biotite; an extremely small quantity of spinel, apatite, and pyrite; a very little garnet, as a border round the iron-ore, rarely round the ferromagnesian silicates; also alteration-products, which are present, however, only in very small quantity. Olivine was not observed in any of the slides.

The porphyritic labradorite.—This mineral is thick-tabular along M(010) and bounded by M(010), P(001), 1(110), T($1\bar{1}0$), and also as far as could be seen by x($10\bar{1}$), perhaps too by y($20\bar{1}$). It occurs in Carlsbad twins, with occasional albite-twinning and subordinate pericline-twinning. Its delimitation from the ground-mass is sharp. Between the very large phenocrysts occur smaller ones of exactly similar character. On the cut and polished surface, of which part is shown in fig. 1 (p. 82), are seen phenocrysts of all sizes, ranging from about 60 square centimetres down to 1 or 2. The distance between the centres of the large phenocrysts on the surface illustrated in fig. 1 varies mostly from 8 to 18 centimetres.

As to the different composition of the plagioclase in the phenocrysts and in the ground-mass, it is seen macroscopically that the porphyritic plagioclase is violet-brown, a colour such as is produced by the ordinary microlithic interpositions, while the plagioclase of the ground-mass is light grey with only a slight tinge of brown. A separation of the ground-mass-minerals, first with a horseshoe-magnet, then with an electro-magnet, and lastly with Sonstadt's solution, was carried out by my son Mr. Th. Vogt, mineralogical student.

(1) The specific gravity was determined by means of the Westphal balance, in combination with the heavy liquid, and yielded the following results:—

(*a*) Porphyritic plagioclase; the bulk was of sp. gr. = 2·708, and some lighter particles, occurring in very small quantity, were only a few thousandths lower.

(*b*) Ground-mass-plagioclase; sp. gr. = 2·685. There was no question as to these differences in specific gravity having been correctly determined.

(2) The chemical composition.—Analysis No. 1 (average of four analyses carried out by students in the Christiania University Metallurgical Laboratory under my direction) is of the phenocrysts. The material for these analyses was a little impure, to the extent of 1 or 2 per cent., owing to the presence of small quantities of magnetite, biotite, and pyroxene.

Analysis No. 2 was carried out by Mr. Th. Vogt on isolated ground-mass-plagioclase (sp. gr. = 2·685), of the same large block (illustrated in fig. 1) as Analysis No. 1.

For comparison, especially with the porphyritic plagioclase, I also append an analysis, carried out in my own laboratory, of labradorite (with a small admixture of iron-ore and ferromagnesian silicates) from the labradorite-rock at Andopen on Flakstadö, $3\frac{1}{2}$ kilometres south of the porphyritic labradorite-norite.

	Labradorite of labradorite-norite.		*Labradorite of labradorite-rock.*	
	Pheno-cryst.	Ground-mass.		
	No. 1.	No. 2.		No. 3.
SiO_2	52·42	55·18	SiO_2	53·34
Al_2O_3	31·25[1]	29·02[2]	TiO_2	0·29
CaO	11·98	10·02	Al_2O_3	30·19[2]
Na_2O	3·44	4·88	MgO	0·44
K_2O	0·97	1·00	CaO	10·89
			Na_2O	3·90
			K_2O	0·82
Totals ...	100·06	100·10	Total ...	99·87

[1] Including a little ferric oxide and titanium-oxide.
[2] Including a very little ferric oxide.

(3) Extinction-angle.—In slices cut along the cleavage of the phenocrysts the average of many observations was :—

	Large phenocrysts.			*Phenocrysts.*	
	Centre.	Outer parts mostly.	Outer parts, certain zones.	Most places.	Certain zones.
≠001	$-6\frac{3}{4}°$	$-5\frac{3}{4}°$		$-6\frac{3}{4}°$	
≠010	$-19\frac{1}{2}°$	$-18\frac{1}{2}°$	down to $-14°$.	$-19\frac{1}{2}°$	down to $-12°$

The porphyritic plagioclase thus shows in most places extinction-angles of about $-6\frac{3}{4}°$ and $-19\frac{1}{2}°$. In sections parallel to 010 of the phenocrysts near the border or 'shell,' a few zones are seen exhibiting a smaller extinction-angle and consequently with somewhat more albite. In the slice of the ground-mass a section sensibly parallel to 010 gave an extinction-angle of only about $-9°$. In sections of the phenocrysts parallel to 010, the angle b (between the twin-striation on the pericline-law and the cleavage 001) was determined as about 3°.

From these observations of the specific gravity, the chemical composition, and the extinction-angles, which correspond well with each other, it is seen that the ground-mass-plagioclase is somewhat richer in albite than the porphyritic plagioclase.

The porphyritic labradorite consists (according to Analysis

No. 1) approximately of 61 per cent. of anorthite, 33 of albite, and 6 of orthoclase (certain peripheral zones are a little richer still in albite). The ground-mass-labradorite consists (as shown by Analysis No. 2) almost exactly of 52 per cent. of anorthite, 42 of albite, and 6 of orthoclase.

To these correspond the calculated compositions Nos. 1 *b* & 2 *b*:—

	No. 1 *b*.	No. 2 *b*.
SiO_2	52·99	55·30
Al_2O_3	29·84	28·29
CaO	12·26	10·45
Na_2O	3·90	4·95
K_2O	1·01	1·01
Totals	100·00	100·00

According to the precise determinations of Messrs. Day & Allen (cited below) the specific gravities are as follows:—

Pure anorthite ($CaAl_2Si_2O_8$) .... 2·765
Pure albite ($NaAlSi_3O_8$) .... 2·605
Orthoclase ($KAlSi_3O_8$) may be put at 2·57.

By a percentage calculation the following specific gravities are obtained:—

Specific gravities.	*Calculated.*	*Found.*
61An, 39Ab, 6Or	2·701	2·708
52An, 42Ab, 6Or	2·686	2·685

The small difference discernible between 'calculated' and 'found' may be taken as confirming the approximate accuracy of the compositions calculated for the two plagioclases on the basis of Analyses Nos. 1 & 2.

In most statements hitherto published regarding the optical constants and specific gravities of the plagioclases, only the influence of anorthite and albite has been considered. Yet, in fact, most plagioclases of eruptive rocks are ternary mixed crystals with a small proportion of orthoclase, the influence of which on the physical constants must also be taken into account.

The pyroxene-minerals.—In the ground-mass diallage and hypersthene occur in approximately equal quantities, both showing the customary interpositions and occasionally having a common crystallographic orientation.

The hypersthene occurs in two varieties: the one with weaker interference-colours and less marked pleochroism; the other with somewhat stronger interference-colours and more vivid pleochroism. The latter variety is, therefore, richer in the ferrous silicate. This variety is occasionally found in belts round the first-named, and is thus of relatively later formation. Both kinds of hypersthene are, judging from their interference-colours and pleochroism, comparatively rich in silicate of magnesia and relatively poor in silicate of iron.

Garnet is found in very small quantities, in the well-known zones surrounding the iron-ore, sometimes also round the ferromagnesian silicates, namely, where these abut against plagioclase. This garnet-border does not belong to the epoch of crystallization, and need not be further considered.

Chemical composition of the ground-mass and its percentages of minerals.—In my laboratory two analyses of the ground-mass were made: No. 4 (four very closely agreeing parallel analyses by my students, Mr. C. Carstens & Mr. R. Marstrander) of the large block already repeatedly mentioned (see fig. 1, p. 82, and Analyses Nos. 1 & 2), and No. 5 (by my student Mr. A. Petterson) of another sample.

CHEMICAL ANALYSES OF THE GROUND-MASS OF THE PORPHYRITIC LABRADORITE-NORITE.

	No. 4.	No. 5.
SiO_2	47·75	46·22
TiO_2	1·74	0·30
Al_2O_3	18·71	20·18
Fe_2O_3	6·08	15·00 (with FeO)
FeO	7·11	
MgO	5·32	5·75
CaO	9·47	9·38
Na_2O	2·70	3·31
K_2O	1·20	1·29
P_2O_5	0·05	0·19
Totals	100·13	(101·62)
Less oxygen in Fe_2O_3		about 1·00
Total (less O in Fe_2O_3)		about 100·62

No. 5 shows a very little more iron-ore and ferromagnesian silicate than No. 4; and further, the rock, as observed under the microscope, showed more apatite. The determination of titanium-oxide in No. 4 is probably a little too high, and in No. 5, on the other hand, somewhat too low.

Mr. Th. Vogt extracted, with the aid of a horseshoe-magnet, from the ground-mass of No. 4 9·9 per cent. of somewhat impure titano-magnetite, the analysis of which showed 80·41 per cent. of soluble ore, with 5·29 of titanium-oxide. There was thus extracted with the magnet 7·96 per cent. of titanomagnetite; if we add the small losses of titanomagnetite, the actual quantity of this ore present in the rock may be taken at about 9 per cent.

The so-called 'titanomagnetite' consists, as is well known, in most (if not in all) cases of a mechanical mixture of magnetite, with mere traces of titanium-oxide, or without any at all, and ilmenite. As regards Norwegian occurrences, I may refer in this respect to a small paper of my own in the 'Norsk Teknisk Tidsskrift,' Christiania, January 1908, and to a more detailed investigation, which will soon be published by my present assistant, Dr. P. Farup. I take for granted below that the titanomagnetite here mentioned consists of 10·05 per cent. of ilmenite, $FeTiO_3$ (=5·29 per cent. TiO_2), and 89·95 per cent. of magnetite, Fe_3O_4. It does not influence the theoretical considerations set forth later whether these last calculations are quite exact or not.

According to estimation, the quantity of biotite present is about 3 per cent. The 0·05 per cent. of phosphorus pentoxide found represents 0·12 per cent. of apatite. The quantity of spinel is only about 0·01 per cent., and may be left out of consideration in the calculations tabulated below, this being also the case with the iron-pyrites.

The 0·5 per cent. of secondary hornblende is taken as having the same composition as the pyroxene-mineral from which it has been formed. The very small quantity of garnet in No. 4, only about 0·5 per cent., is left out of consideration, or, rather, is considered as chiefly consisting of plagioclastic material.

The composition of the ground-mass minerals is known in the case of some: labradorite (No. 2 *b*), titanomagnetite, and apatite; for the others the compositions set forth in the following table are assumed:—

Hypersthene.		*Diallage.*	
Per cent.		Per cent.	
60	$Mg_2Si_2O_6$.	60	$CaMgSi_2O_6$.
20	$Fe_2Si_2O_6$.	20	$CaFeSi_2O_6$.
13	$FeCaSi_2O_6$.	10	$Fe_2Si_2O_6$.
5	$FeAl_2SiO_6$.	6	$FeAl_2SiO_6$.
2	$FeFe_2SiO_6$.	4	$FeFe_2SiO_6$.

For biotite a composition corresponding with the analyses of biotite from other gabbro-rocks is assumed. Further, the presence of a small quantity of titanium-oxide is assumed in the pyroxene-minerals.

Composition of the Ground-mass Minerals.

	Titano-magnetite.	*Plagio-clase.*	*Biotite.*	*Hyper-sthene.*	*Diallage.*
SiO_2	......	55·30	38	52·3	49·1
TiO_2	5·29	......	2	0·8	0·8
Al_2O_3	......	28·29	17	2·2	2·6
Fe_2O_3	62·03	......	7	1·1	2·2
FeO	32·68	......	5	16·7	14·2
MgO	......	......	21	24·0	11·1
CaO	......	10·45	......	2·9	20·0
Na_2O	......	4·95	1·5		
K_2O	......	1·01	8·5		
Totals ...	100·00	100·00	100·00	100·00	100·00

The composition of the ground-mass of No. 4 is calculated approximately as follows:—

	9 per cent. *Titano-magnetite.*	61·88 p.c. *Plagio-clase.*	3 p. c. *Bio-tite.*	13 p. c. *Hyper-sthene.*	13 p. c. *Dial-lage.*	0·12 p.c. *Apa-tite.*	*Total calcu-lated.*	*Total found.*
SiO_2 ...	...	34·22	1·14	6·80	6·38	...	48·54	47·75
TiO_2 ...	0·48	...	0·06	0·10	0·10	...	(0·74)	1·74
Al_2O_3 ...	...	17·51	0·51	0·29	0·34	...	18·65	18·71
Fe_2O_3 ...	5·58	...	0·21	0·14	0·29	...	6·22	6·08
FeO ...	2·94	...	0·15	2·17	1·85	...	7·11	7·11
MgO ...	...	...	0·63	3·12	1·44	...	5·19	5·32
CaO ...	...	6·47	...	0·38	2·60	0·07	9·52	9·47
Na_2O ...	...	3·06	0·05	...	...	...	3·11	2·70
K_2O ...	...	0·62	0·26	...	...	...	0·88	1·20
P_2O_5 ...	...	...	...	...	...	0·05	0·05	0·05
Totals...	9·00	61·88	3·01	13·00	13·00	0·12	100·01	100·13

The concordance between 'calculated' and 'found' is sufficiently close to show that errors of any importance are practically impossible.[1]

To simplify matters, I calculate the components RAl_2SiO_6, RFe_2SiO_6, and also $Ca(Fe, Mg)Si_2O_6$ in hypersthene and $(Fe, Mg)_2 Si_2O_6$ in diallage only as respectively $FeAl_2SiO_6$, $FeFe_2SiO_6$, $CaFe Si_2O_6$, and $Fe_2Si_2O_6$. In reality there may be besides these also some $MgAl_2SiO_6$, $MgFe_2SiO_6$, $CaMgSi_2O_6$, and $Mg_2Si_2O_6$; this is, however, not taken into consideration either here or further on.

[1] It may be remarked, however, that the small quantity of titanium-oxide in the ferromagnesian silicates is perhaps estimated a little too low, and the silica correspondingly a little too high.

The percentage of single components in the ground-mass is approximately as follows:—

61·88 per cent. plagioclase (52An, 42Ab, 6Or)	32·2 per cent.	$CaAl_2Si_2O_8$		
	26·0 ,,	$NaAlSi_3O_8$		
	3·7 ,,	$KAlSi_3O_8$		
9 per cent. titano-magnetite	8·1 ,,	Fe_3O_4		
	0·9 ,,	$FeTiO_3$		
13 per cent. hypersthene	7·8 ,,	$Mg_2Si_2O_6$		
	2·6 ,,	$Fe_2Si_2O_6$		
	1·7 ,,	$CaFeSi_2O_6$	7·8 per cent.	$Mg_2Si_2O_6$
	0·6 ,,	$FeAl_2SiO_6$	7·8 ,,	$CaMgSi_2O_6$
	0·3 ,,	$FeFe_2SiO_6$	4·3 ,,	$CaFeSi_2O_6$
13 per cent. diallage	7·8 ,,	$CaMgSi_2O_6$	= 3·9 ,,	$Fe_2Si_2O_6$
	2·6 ,,	$CaFeSi_2O_6$	1·4 ,,	$FeAl_2SiO_6$
	1·3 ,,	$Fe_2Si_2O_6$	0·8 ,,	$FeFe_2SiO_6$
	0·8 ,,	$FeAl_2SiO_6$		
	0·5 ,,	$FeFe_2SiO_6$		
3 per cent. biotite.........	several components in small quantity.			

0·12 per cent. apatite.

Also about 0·01 per cent. of spinel and about the same quantity of iron-pyrites.

Chemical composition and mineral percentages of the rock as a whole.—From the cut surface of the big block (see fig. 1 & Analyses 1, 2, & 4) almost a third of a square metre in area, the phenocrysts were drawn on millimetre-paper and the contours further corrected afterwards. On a surface of 2400 cm.^{2} the phenocrysts represented about 612 cm.^{2}, being about 25·5 per cent. by volume. Considering the specific gravity of the phenocrysts (2·708) and of the ground-mass (about 3·00), we get the result that the phenocrysts in the present case represent very nearly 23 per cent. of the total weight. In other samples the phenocrysts are sometimes more, sometimes less plentiful. Below we are only concerned with the big block (Analyses 1, 2, & 4). The composition of the whole rock may be calculated as from 23 per cent. phenocrysts (No. 1*b*) and 77 per cent. ground-mass (No. 4).

Composition of the Porphyritic Labradorite-Norite (Nos. 1, 2, & 4).

	No. 6.
SiO_2	48·96
TiO_2	1·34
Al_2O_3	21·27
Fe_2O_3	4·68
FeO	5·47
MgO	4·10
CaO	10·11
Na_2O	2·97
K_2O	1·16
P_2O_5	0·04
Total	100·10

Taking into consideration the fact that the porphyritic plagioclase amounting to 23 per cent. consists of 61 anorthite, 33 albite, 6 orthoclase, and that the plagioclase amounting to 62 (or 61·88) per cent. in the 77 per cent. of ground-mass consists of 52 anorthite, 42 albite, 6 orthoclase, the components of the whole rock are thus :—

70·65 per cent. plagioclase (An, Ab, Or)	38·81 per cent.	$CaAl_2Si_2O_8$		
	27·60 ,,	$NaAlSi_3O_8$		
	4·24 ,,	$KAlSi_3O_8$		
7·0 per cent. titano-magnetite	6·3 ,,	Fe_3O_4		
	0·9 ,,	$FeTiO_3$		
10 per cent. hypersthene	6·0 ,,	$Mg_2Si_2O_6$		
	2·0 ,,	$Fe_2Si_2O_6$		
	1·3 ,,	$CaFeSi_2O_6$	6·0 per cent.	$Mg_2Si_2O_6$
	0·46 ,,	$FeAl_2SiO_6$	6·0 ,,	$CaMgSi_2O$
	0·23 ,,	$FeFe_2SiO_6$	3·3 ,,	$CaFeSi_2O_6$
10 per cent. diallage ...	6·0 ,,	$CaMgSi_2O_6$	= 3·0 ,,	$Fe_2Si_2O_6$
	2·0 ,,	$CaFeSi_2O_6$	1·1 ,,	$FeAl_2SiO_6$
	1·0 ,,	$Fe_2Si_2O_6$	0·6 ,,	$FeFe_2SiO_6$
	0·6 ,,	$FeAl_2SiO_6$		
	0·38 ,,	$FeFe_2SiO_6$		
2·3 per cent. biotite	several components in small quantity.			
0·09 per cent. apatite.				

On the Order of Crystallization.

It is evident that the labradorite-phenocrysts were separated out before the interstitial minerals. Further, it may be presumed that the crystallization of the very large phenocrysts began at a somewhat earlier stage than the smaller phenocrysts occurring between the large ones.

The crystallization of the labradorite began at certain points ('centres of crystallization') lying from 8 to 18 centimetres apart. And, when this crystallization had gone on for some time, a crystallization of plagioclase began round new centres. The inclusions in the phenocrysts are dealt with below.

When the separation of the phenocrysts had come to an end, the ground-mass began to solidify, this taking place at first with a contemporaneous crystallization of magnetite and labradorite. That the magnetite crystallized before the mica and the pyroxene-minerals is seen from the fact that the latter are frequently deposited round the magnetite-individuals. It is further very frequently observed that a particularly large quantity of magnetite occurs immediately round the margins of the labradorite-phenocrysts, this being the case with the small as well as with the large ones. In a zone about 5 millimetres broad round the labradorite-

phenocrysts may be frequently seen about double the quantity of magnetite that occurs in the rest of the ground-mass.[1] On the other hand, no corresponding enrichment of the ferromagnesian silicates round the phenocrysts has taken place.

The zone that is somewhat richer in magnetite is frequently found entirely enveloping the phenocrysts, not only on the upper side but also on the lower; thus the phenomenon cannot be explained as the effect of gravity. It may be connected with the relatively low temperature at the epoch of crystallization and the consequently rather high viscosity of the solution. The crystals of magnetite have partly been deposited on the solid bodies in the liquid; evidence of such a process is very often met with.

The magnetite-individuals do not show an idiomorphic outline against the plagioclase of the ground-mass; hence, it may be inferred that the separation of the plagioclase has continued during the crystallization of the magnetite. It could not be determined whether a very brief interruption of the plagioclase-crystallization had taken place on account of super-saturation.[2]

At a later stage, biotite, hypersthene, and diallage began to crystallize. That the separation of magnetite and plagioclase still continued is shown by the non-idiomorphic boundary of these two ground-mass minerals against the ferromagnesian silicates. Further, I would call attention to the following point:—The magnetite-individuals completely embedded or enclosed in the hypersthene and diallage are on an average essentially smaller than the magnetite-individuals not thus completely enveloped by the ferromagnesian silicates. This may be explained by the continued crystallization of these latter magnetite-individuals after the ferromagnesian silicates had begun to crystallize.

We may consequently distinguish between the following three stages of crystallization:

(1) first, plagioclase alone;
(2) then plagioclase and magnetite contemporaneously;
(3) lastly, plagioclase, magnetite, and pyroxene-minerals, besides biotite, contemporaneously.

The separation of the porphyritic labradorite-crystals continued until that of the magnetite began.

The gradual change in the composition of the plagioclase and hypersthene during the period of crystallization is further dealt with below.

The intimate intergrowth, with common crystallographic orientation, of hypersthene and diallage, which has been occasionally observed, may have been caused by the contemporaneous crystallization of these two minerals.

The inconsiderable quantity of spinel (pleonaste), estimated at

[1] See fig. 1 (p. 82) near the bottom on the right side, and other places.

[2] See my papers in Tscherm. Min. Petrogr. Mitth. vol. xxiv (1905) p. 445, & vol. xxvii (1908) p. 171.

only about 0·01 per cent., occurs as inclusions in the magnetite. The crystallization of the spinel probably took place after the separation of the labradorite-phenocrysts had been completed.

Quite small quantities of apatite are sometimes observed in microscopic sections of the ground-mass, but never in the numerous slides prepared from the labradorite-phenocrysts; this is an indication that the crystallization of the apatite began relatively late. A definite conclusion on this question is, however, not possible in the present case.

The labradorite-phenocrysts contain, besides the ordinary microlithic interpositions, some inclusions of magnetite, biotite, hypersthene, and diallage, these inclusions being estimated at about one-half per cent. of the phenocrysts, in some sections rather more, in others less or nothing at all.

The minerals in these inclusions occur, according to estimation, in the same proportions as in the ground-mass, but in much smaller individuals, of only about one-fifth of the size of those in the ground-mass. The enclosed minerals do not show idiomorphic outlines against their 'host,' the plagioclase. The inclusions as a rule lie with their longitudinal dimension approximately parallel to the cleavage-planes—that is, the most important planes of growth—of the plagioclase. Frequently the enclosed minerals are accompanied by plagioclose in quite small individuals and having a different orientation from that of the 'host.' In other cases, one finds in the immediate neighbourhood of the inclusions plagioclase having the same orientation as that of the 'host,' but a somewhat different extinction-angle, thus showing some difference in chemical composition.

These inclusions are, according to the foregoing observations, small portions of the mother-liquor, enveloped by the growth of the plagioclase, and crystallized during the later cooling. We may recall the well-known inclusions of glass, that is, of mother-liquor, in crystals of leucite, etc. In these last cases the inclusions solidified in an amorphous condition, but in the case of the labradorite-norite the inclusions necessarily solidified in crystalline form just as in the ground-mass, on account of the slowness of the rate of cooling. The felspathic components present in the liquid inclusions, nAn, mAb, oOr, crystallized sometimes in small independent individuals and sometimes in the same crystallographic orientation as the 'host.'

Physico-chemical Explanation of the Order of Crystallization.

To illustrate the order of crystallization in a ternary system consisting of mutually independent components, I use a graphic representation[1] (fig. 2 a), with a horizontal projection (fig. 2 b).

[1] See, for instance, my paper on 'Physikalisch-chemische Gesetze der Krystallisationsfolge in Eruptivgesteinen' Tscherm. Min. Petrogr. Mitth. vol. xxiv (1905) figs. 3 a & 3 b, on p. 442.

In fig. 2 *a* the perpendicular lines signify the temperature; T_a, T_b, and T_c are the melting-points of *a*, *b*, & *c*. For the binary combinations $a:b$, $a:c$, and $b:c$ (see fig. 2 *a*) we have the curves of solidification $T_a—E_{a-b}$, $T_b—E_{a-b}$, etc., as well as the binary eutectics E_{a-b}, E_{a-c}, and E_{b-c}. For the ternary combination $a:b:c$ we have the surfaces of solidification, $T_a—E_{a-b}—E_{a-b-c}—E_{a-c}$, etc., which cut each other in the 'eutectic curves' $E_{a-b}—E_{a-b-c}$, etc. The point of intersection of the three surfaces of solidification, namely the ternary eutectic point E_{a-b-c}, shows a lower temperature than the lowest of the three binary eutectics E_{a-b}, E_{a-c}, and E_{b-c}.

Fig. 2 *a*.

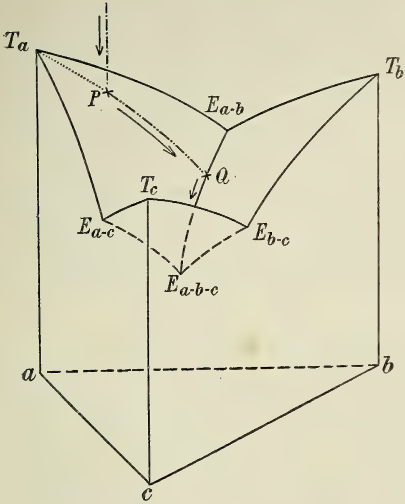
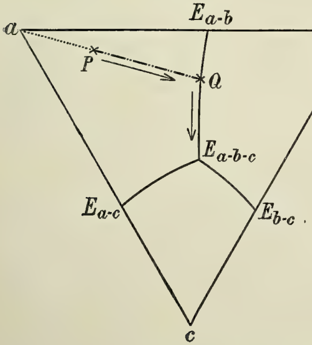


Fig. 2 *b*.



We may now follow the process of crystallization of a ternary solution consisting of *a*, *b*, & *c*, and having a composition *P*. We are assuming that no supersaturation takes place.

On cooling down to the point *P* on the surface of solidification $T_a—E_{a-b}—E_{a-b-c}—E_{a-c}$, *a* begins to separate out. By this separating-out of *a*, the relative proportion between *b* and *c* in the solution is not

changed. By continued cooling the separation of a is completed along a curve P—Q in fig. $2a$, which curve is shown by a straight line P—Q in the projection (fig. $2b$). At Q commences a simultaneous crystallization of a & b, which with falling temperature proceeds along the curve Q—E_{a-b-c}. At last, with constant temperature at the ternary eutectic E_{a-b-c}, the solidification of c as well as of the rest of a & b takes place.

We have thus three stages of crystallization here:—(1) separation of a alone, (2) then of a and b simultaneously, and (3) lastly of all three components simultaneously in the ternary eutectic mixture.

The complications which may be caused by supersaturation or undercooling need not be treated of here. Regarding these points I would refer to the treatment of them in my papers in Tscherm. Min. Petrogr. Mitth. vols. xxiv, xxv, & xxvii (1905–1908).

The ground-mass, after the crystallizing alone of a on the curve P to Q, represents the composition of the mutual solution at the point Q, that is at a point of the eutectic curve E_{a-b}—E_{a-b-c}.

In magmas the laws of the sequence of crystallization are generally much more complicated than in the simple case described here, which contains only three mutually independent components. Magmas contain generally quite a number of components, among which only some are mutually independent. Almost without exception, some components stand in mixed-crystal relation to each other. Then it must also be borne in mind that, as a rule, several components have an ion in common. In the porphyritic labradorite-norite here described, we thus find, as may be seen from the enumeration on p. 90, at least eighteen different components, among which some, however, occur only in small quantity.

As I have explained in earlier memoirs, we may generally presume that the components occurring in solidified rocks were present also in the original solution.[1] To these must of course be added components in which water, carbon-dioxide, etc., played a part, although undoubtedly they were present as a rule only in comparatively small quantity in basic magmas. The percentage has been so small, that the influence of these components on the crystalline succession may be left wholly or nearly out of consideration. Consequently I shall here take no notice of these compounds of water, carbon-dioxide, etc.

The plagioclastic components, anorthite and albite, besides a little orthoclase, may be looked upon as a unity when compared with the other components.

The hypersthene-components $Mg_2Si_2O_6$, $Fe_2Si_2O_6$, etc. may likewise be classed together as against the magnetite and plagioclase;

[1] See principally 'Die Silikatschmelzlösungen' I & II, in Vidensk. Selsk. Skrifter, Kristiania, 1903 & 1904; and the above-mentioned paper in Tscherm. Min. Petrogr. Mitth. vol. xxiv (1905). The same theoretical view has been lately maintained by Mr. Alfred Harker, 'Igneous Rock-Magmas as Solutions' (Science Progress, Oct. 1907), with reference to my previous works.

indeed, probably the whole of the pyroxenic components—that is, not only the hypersthene, but also the diallage-components—may essentially be classed together as a unity, as against the other minerals.

Magnetite is an independent component, as against plagioclase and pyroxene.

The components occurring in quite small quantity—mica, apatite, spinel, and iron-pyrites, besides ilmenite—have, in all probability, because of their small percentage, had but little, if any, influence on the sequence of crystallization of the plagioclase, magnetite, and pyroxene; or, because they have an ion in common with several other components, at all events only an insignificant influence.[1] As regards the study of the processes of crystallization of the three chief minerals just mentioned, they may thus be left out of consideration.

After subtracting the mica, apatite, spinel, pyrites (besides ilmenite), and re-calculating the sum-total of the chief minerals to 100 per cent., we get the following mixture in the original solution:

72·8 per cent. of plagioclase-components.
6·5 per cent. of magnetite-components (Fe_3O_4).
20·7 per cent. of pyroxene-components.

Regarding the crystallization of plagioclase and magnetite, these three components—or, let us say, groups of components—may be looked upon essentially as independent one of the other, although several have an ion in common (Ca in $CaAl_2Si_2O_8$ and $CaMgSi_2O_6$, $CaFeSi_2O_6$, etc.; Fe in $FeFe_2O_4$ and $Fe_2Si_2O_6$, etc.).

According to the foregoing observations we find in the labradorite-norite here described the following three stages of crystallization: (1) first plagioclase alone, (2) then plagioclase and magnetite simultaneously, and (3) plagioclase, magnetite, and pyroxenic mineral (or minerals) simultaneously. If, then, we confine ourselves to the chief minerals, and if we provisionally look upon the two pyroxenic minerals as one unit, we find here the same three stages of crystallization as in the ordinary ternary systems consisting of independent components.

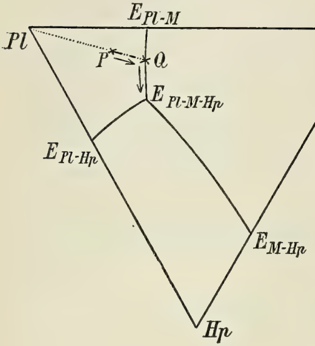
Consequently, to the processes of crystallization in this magma may be applied the physico-chemical laws which have been mentioned above (pp. 93–94 and figs. 2 *a* & 2 *b*) as applying to a ternary system in general. The reservation must, however, be made that the composition of the plagioclase changes somewhat during its separation, and that our 'pyroxenic mineral' is not a single unit. The following diagram (fig. 3, p. 96) though not quite exhaustive, may nevertheless illustrate the most important processes of crystallization with which we are here concerned.

In this diagram *Pl*, *M*, and *Hp* represent respectively pure plagioclase, magnetite, and hypersthene (or pyroxenic mineral); $E_{Pl\text{-}M}$,

[1] On the significance of a common ion in the order of crystallization I would refer to certain passages of my memoirs already cited.

$E_{Pl\text{-}Hp}$, and $E_{M\text{-}Hp}$ are the binary eutectics (in the drawing they are rather arbitrarily placed) between plagioclase and magnetite, plagioclase and hypersthene (or pyroxenic mineral), magnetite and hypersthene (or pyroxenic mineral); and $E_{Pl\text{-}M\text{-}Hp}$ is the ternary eutectic point.

Fig. 3.



P represents the composition of the original solution (72·8 per cent. Pl, 6·5 per cent. M, 20·7 per cent. Hp). The crystallization of the plagioclase alone—in the phenocrysts, to the amount of 23 per cent. of the original solution—takes place along the curve P—Q; and at Q the simultaneous crystallization begins of plagioclase and magnetite, along the curve Q—$E_{Pl\text{-}M\text{-}Hp}$. As there are in the present case two pyroxenic minerals, the simple ternary diagram is not applicable to the final crystallization.

The composition of the point Q is found from Analysis 4, eliminating the small admixtures of biotite, spinel, etc. and recalculating the rest to 100 per cent. We shall then obtain the following mixture:—

64·5 per cent. of plagioclase.
8·8 per cent. of magnetite (Fe_3O_4).
27·0 per cent. of hypersthene-diallage.

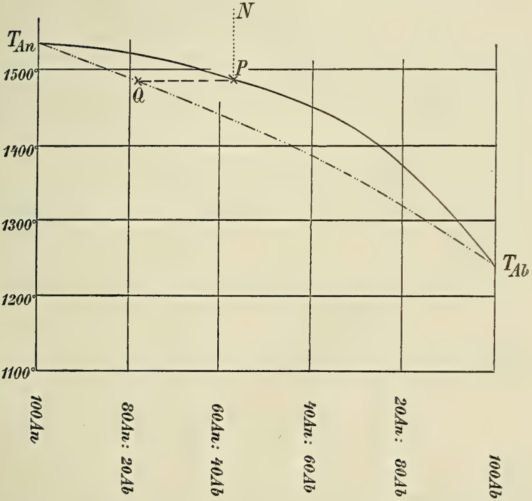
This composition tells us that with more plagioclase-component in the solution plagioclase crystallizes first; with more magnetite-component in the solution, on the other hand, magnetite crystallizes first. By similar investigations in the future, we shall, without doubt, succeed in fixing a whole series of such points on the eutectic lines. The investigation will be complicated, however, by the presence of so many components, especially among the pyroxene-minerals.

The composition of the point $E_{Pl\text{-}M\text{-}HP}$ with diallage or hypersthene may be called 'the ternary gabbroidal eutectic.' If the composition of this point be determined, we shall travel far along the way to the study of the sequence of crystallization in gabbroidal magmas.

On the equilibrium between the solid and the liquid anorthite + albite-phase.—According to the analytical

method used by me and the synthetical method followed by Messrs. Arthur L. Day & E. T. Allen,[1] both of which entirely different methods of research lead to the same result, the binary mixed-crystal combination An : Ab belongs to Roozeboom's Type I. For explanation I reproduce, from my paper in Tscherm. Min. Petrogr. Mitth. vol. xxiv (1905) fig. 15 on p. 514, the accompanying fig. 4. The upper unbroken line indicates the curve of solidification, and the lower broken line the curve of composition of the first

Fig. 4.



separated mixed crystal; if melted An+Ab of composition *N* is cooled to the point *P*, then, no account being taken of supersaturation, a plagioclase of composition *Q* first crystallizes out.

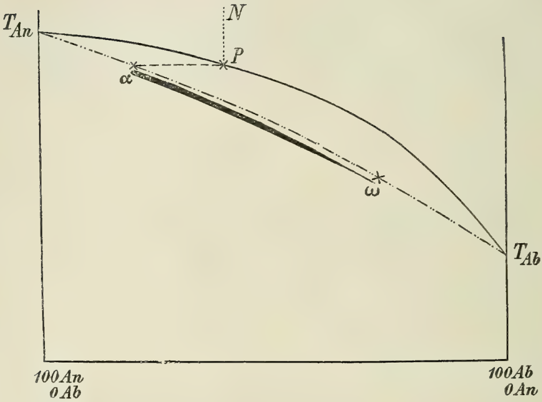
The first mixed crystal crystallizing out of a molten solution with given proportions of An : Ab has approximately the following composition[2] :—

Out of solutions of:	*the first crystal contains*:
60 An : 40 Ab	about 80 An : 20 Ab.
40 An : 60 Ab	about 65–60 An : 35–40 Ab.

[1] 'Isomorphism & Thermal Properties of the Felspars' Carnegie Institution of Washington, Publ. 31, 1905.

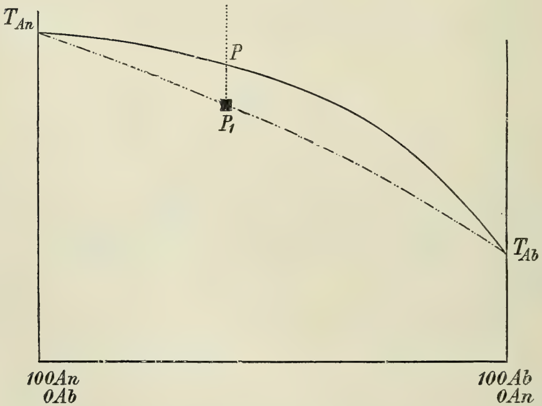
[2] See my paper in Tscherm. Min. Petrogr. Mitth. vol. xxiv (1905) pp. 512–14.

Fig. 5.



T_{An}
N
P
α
ω
T_{Ab}
100An
0Ab
100Ab
0An

Fig. 6.



T_{An}
P
P_1
T_{Ab}
100An
0Ab
100Ab
0An

When some plagioclase has separated out, the proportion between anorthite and albite in the solution changes, anorthite decreasing, albite, on the other hand, increasing. Consequently there is no longer equilibrium between the solid and the liquid phase. If the conditions for equilibrium exist, an exchange takes place between the solid and the liquid phase, some anorthite leaving the already solidified plagioclase-crystals and some albite entering into them.

When there is a total want of equilibrium during the process of crystallization stages of plagioclase succeed each other with a very considerable difference between the first (α) and the last (ω) mixed crystal (see fig. 5, p. 98).

With complete equilibrium there results as the last product of crystallization a plagioclase (P_1) with the same proportion An : Ab as in the solution (see fig. 6, p. 98).

The first case is met with, although perhaps never in its extreme form, in the relatively quickly solidified dyke- and effusive surface-rocks, the difference between the first (α) and the last (ω) plagioclase being occasionally as much as that between bytownite and andesine-oligoclase.

In the case of the labradorite-norite here described there has been a partial—and only a partial—equilibrium between the solid and the liquid An + Ab-phase. Our rock contains :—

23 per cent. of phenocrysts with	61 An : 33 Ab : 6 Or ;
77 per cent. of ground-mass, containing 61·88 per cent. of plagioclase with	52 An : 42 Ab : 6 Or ;
the average proportion in the whole rock thus being	55 An : 39 Ab : 6 Or.

This also represents the An : Ab : Or-proportion in the magma before the crystallization of the rock. The small quantity of orthoclase may be left out of consideration in the following investigation. We then get :—

In the solution........................	58·5 An : 41·5 Ab,
,, ,, phenocrysts	65 An : 35 Ab,
,, ,, ground-mass	55·3 An : 44·7 Ab.

As the solidification of the rock here described proceeded very slowly, the crystallizatien of the first mixed crystal must have taken place with but little, if any, supersaturation. Of the solution 58·5 An : 41·5 Ab (or, if Or be considered, 55 An : 39 Ab : 6 Or) a mixed crystal of the composition about 78 An : 22 Ab (or about 77 An : 20 Ab : 3 Or) has first separated out. This, as well as the following mixed crystals, has—in the 'porphyritic' period, during the crystallization of plagioclase alone—been approximately in equilibrium with the solution, the result being porphyritic crystals of the composition 65 An : 35 Ab (or, if Or be considered, 61 An : 33 Ab : 6 Or). In their outer shell the porphyritic crystals are somewhat poorer still in anorthite and richer in albite.

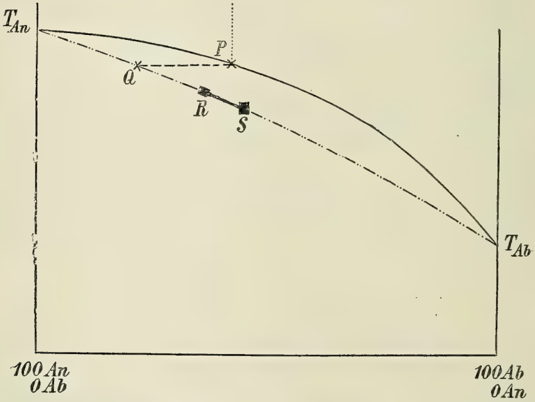
During the crystallization of the ground-mass the equilibrium—or approximate equilibrium—between the porphyritic plagioclase-crystals and the plagioclase-components in the remaining solution

ceased. This may probably depend on the considerable size of the phenocrysts in connexion with the viscosity of the solution increasing as the crystallization-temperature diminished.

In order to explain the result, I give here a graphic illustration, leaving the small quantity of orthoclase unconsidered; in fig. 7 *P* represents the original relative proportion An : Ab (58·5 An : 41·5 Ab) of the solution; *Q*, the composition of the first mixed crystal; *R*, the composition (65 An : 35 Ab) of the phenocrysts or most of them; and *S*, that of the plagioclase in the ground-mass (55·3 An : 44·7 Ab). As the outer shell of the phenocrysts frequently shows a zone richer in albite, the plane *R* has been continued by a fine line in the direction of *S*.

On the curve *Q*—*R*, that is between about 78 An : 22 Ab and 65 An : 35 Ab, there existed equilibrium—or nearly equilibrium—between solution and mixed crystal; but then the equilibrium ceased, and thus at last plagioclase of composition *S* was evolved.

Fig. 7.



What has been said here of the plagioclase may be applied in the essential points also to the hypersthene. The two chief components of this mineral, namely silicate of magnesia and silicate of iron, pretty certainly belong, as I have pointed out in earlier papers, to mixed crystals of Type I. The mixed crystal first separated out is richer in magnesia and poorer in iron than the later crystals. The border of hypersthene comparatively richer in silicate of iron round that which is somewhat poorer in this component, sometimes observed in the labradorite-norite here described, shows that the equilibrium of the components in question in the solid and liquid phase was not complete.

The hypersthene or enstatite-hypersthene, separated out in the presence of a fairly large quantity of $Ca(Fe, Mg)Si_2O_6$, contains, at the high temperature at which the mineral is formed, about 12 to 15 per cent. of $CaMgSi_2O_6$ or $CaFeSi_2O_6$. By cooling down to ordinary temperature, however, the enstatite-hypersthene cannot carry so much $Ca(Mg, Fe)Si_2O_6$ in solid solution. Consequently some augite is separated out, in perthitic lamellæ—corresponding with the perthitic lamellæ of albite or albite-oligoclase in perthitic striated microcline. I would refer the reader to my explanation regarding this phenomenon in Tscherm. Min. Petrogr. Mitth. vol. xxiv (1905) pp. 541–42 (and fig. 10, compare the lines *J N* & *G M*, p. 484) and to the later published work of Dr. W. Wahl, 'Analogien zwischen Gliedern der Pyroxen- & Feldspat-Gruppen & über die Perthitstrukturen.'[1]

Further, I would remark that the materials of the well-known microlithic interposition—of titanium mineral(?)—in the plagioclase as well as in the diallage and hypersthene of the gabbro-rocks most probably were contained at first in solid solution, and that they separated out on the later cooling down.

On the temperature-interval of the crystallization.—In a solution consisting only of anorthite and albite, of composition 58·5 An : 41·5 Ab, the point P (see fig. 4, p. 97) will, under a pressure of one atmosphere, lie at about 1475° Centigr. When some orthoclase is present in the solution, namely with the proportion 55 An : 39 Ab : 6 Or, the surface of crystallization will be reached at a little lower temperature, namely, at about 1450° (see fig. 12 of my paper in Tscherm. Min. Petrogr. Mitth. vol. xxiv, 1905, p. 506). Considering the lowering influence exercised by the many other components on the plane of crystallization, we may assume that the crystallization of the plagioclase in the rock here described ought to have begun at a temperature of about 1350° or 1350° to 1400° Centigrade, presuming crystallization to have taken place at low pressure. And the end of the crystallization at the eutectic finally reached might be taken to lie at about 1000°. Actually the crystallization took place under a very high pressure; thus the crystallization-temperatures in question were raised, the increase being, however, rather small—as I have explained in an earlier paper (in Tscherm. Min. Petrogr. Mitth. vol. xxvii, 1908). The real interval of crystallization for the rock here described may thus be placed in the stage between about 1400° and about 1000°–1050°.

In my earlier works above cited, it has been my chief object to show that the ordinary physico-chemical laws applying to the phases liquid-solid also hold good as regards the processes of crystallization in magmas.

[1] Öfvers. af Finska Vetensk. Soc. Förh. 1906–1907, printed 1908, No. 2, p. 19.

In his recently published work, 'The Data of Geochemistry' (U. S. Geol. Surv. Bull. No. 330, 1908, p. 249), Dr. F. W. Clarke says on this point:—

'The essential point in Vogt's work is that he attempts to apply modern physico-chemical methods to the investigation of magmas, and whether his conclusions are maintained or not they are at least suggestive.'

I think that by the present investigation of a given eruptive rock, I have established that the processes of crystallization in a magma may be legitimately explained in all their details according to physico-chemical laws, and consequently that my conclusions 'may be maintained.'

The difficulties increase with the number of the components. The natural method of research is, therefore, to begin with rocks containing only one or two principal minerals, and subsequently to study the rocks of more complex composition.

Through physical chemistry the science of petrography has acquired a new method of research, which will throw light upon much that has previously been mysterious in our eyes.

Discussion.

Dr. Teall said that more than twenty years had elapsed since he first recognized the great importance, so far as petrology was concerned, of Prof. Guthrie's researches on cryohydrates and eutectics. During that period great advances had taken place in our knowledge of the laws of solutions, and the Author had done more than any one else in applying these laws to the phenomena of igneous rocks. He (the speaker) had no doubt that the present paper would prove to be an important communication on the subject.

Dr. Flett said that he welcomed this paper as an important contribution to the theory of the crystallization of basic rocks according to physico-chemical laws. The case discussed by the Author, though not exactly similar to any British rock with which the speaker was acquainted, might still be regarded as one of a group of which there were many British representatives. The rapid progress which the study of rocks was making along these lines was most gratifying, and was of cardinal importance to theoretical petrology.

Mr. Barrow drew attention to some minor points, as to which there was room for difference of opinion. Some authorities would call in question the view that the large felspars separated out from the 'fusion-solution' before the iron-ores: the alternative view being that during growth the large crystals forced the already formed grains of iron-ore outwards, so that eventually they formed a thin fringe round the felspars. The larger crystals of the latter were often supposed to have separated out from the magma at a great depth and under a great pressure; and, further, this

separation was essential to reduce the residue to an eutectic mixture of sufficiently low consolidation-point to enable it (under this pressure) to remain liquid at all.

Dr. J. W. Evans thought that there was every reason to believe that, as the previous speaker had suggested, the magnetite had crystallized out before the plagioclase. The Author contended that the plagioclase continued to separate out—with increasing acidity—till there was just sufficient felspathic material left to form an eutectic mixture with the pyroxene. If he were right, the interesting conclusion followed that the acidity of the plagioclase of the ground-mass depended on the amount of pyroxene present. The speaker believed that a long series of careful studies like the present would be required, before the laws that governed the crystallization of minerals from rock-magmas could be worked out.

The President (Prof. Sollas) remarked that the formal thanks of the Society had been emphasized by the warm welcome with which this communication from their esteemed Foreign Member had been received. The lucid exposition by Prof. Watts gave a full account of the investigation. It was evident that the phase-rule was a powerful instrument, which in skilled hands was capable of successful application to many of the deeper problems of petrography. That the simpler problems should be attempted first was natural; more complicated and anomalous cases would be attacked later. The notion of eutectics, introduced by Dr. Teall, was sound, and its study was becoming increasingly fruitful.

Prof. Watts, replying on behalf of the Author, apologized that he had only been able to give an imperfect account of a very lucid paper, the outcome of a great deal of chemical and microscopical work. He stated that the Author had deliberately excluded questions of supersaturation from consideration, and had reduced the eighteen or more actual components of the rock to a minimum of three components or groups of components.

6. *On the* Igneous *and* Associated Sedimentary Rocks *of the* Tourmakeady District (County Mayo). By Charles Irving Gardiner, M.A., F.G.S., and Prof. Sidney Hugh Reynolds, M.A., F.G.S.; with a Palæontological Appendix by Frederick Richard Cowper Reed, M.A., F.G.S. (Read December 16th, 1908.)

[Plates IV–VI.]

Contents.

I. Introduction.

Our object in the present paper is to describe a series of igneous rocks associated with beds containing Ordovician fossils, and occupying a tract of country, having a width of about a mile, which extends along the western shore of Lough Mask from the hamlet of Derrindaffderg in the north to the neighbourhood of Tourmakeady in the south, a distance of about 4½ miles.

At the southern end of the area, on its eastern side, this igneous series of rocks is bounded by massive conglomerates; and rocks lithologically similar, though probably of much later date, form the whole of the western boundary. Along most of the eastern border occur conglomerates and sandstones, to which we, following the Survey, shall refer as the basal beds of the Carboniferous, although they may be regarded with equal probability as representing the Old Red Sandstone.

The surface is undulating, but the physical features are not striking—the ground never rising, in the area with which we deal, to a greater height than about 400 feet, or some 350 feet above

Lough Mask. A number of streams traverse the district from west to east, and afford an excellent series of sections; but, apart from these, exposures are almost everywhere numerous, this being partly due to the fact that the district is free from drift.

Considering the interesting and varied character of its geology, it is remarkable that comparatively little has hitherto been written about this area. In 1874, G. H. Kinahan,[1] in a paper on the 'Geology of West Galway & South-West Mayo,' while in the main dealing with districts farther south, incidentally refers to the Tourmakeady district.

By far the fullest account of the district is that by G. H. Kinahan & R. G. Symes, contained in the Explanation of Sheets 73, 74 (in part), 83, & 84 of the Geological Survey map of Ireland, published in 1876. We shall frequently have occasion to refer to this, but will here merely mention that the igneous series, as a whole, is considered to be of Silurian (Upper Silurian) age, the remarkable limestone-masses with Ordovician fossils, to be described later, being regarded as dislocated blocks which had been carried up by later volcanic eruptions.

Nothing appears to have been written about the district for the next 20 years, but the Annual Report of the Geological Survey for 1896[2] contains an account by Sir Archibald Geikie of Mr. J. R. Kilroe's work, in which the occurrence is mentioned of pre-Bala fossiliferous rocks, and the whole igneous series is considered to be not of Silurian (Upper Silurian) but of Ordovician (Lower Silurian) age. This conclusion is further elaborated in Sir Archibald Geikie's 'Ancient Volcanoes of Great Britain,'[3] where a generalized section across the area is given.

Finally, the paper by Mr. Kilroe, 'On the Silurian & Metamorphic Rocks of Mayo & North Galway,' recently published,[4] contains a number of references to the district with which we are dealing. The most important point in Mr. Kilroe's paper, however, is the conclusion that the coarse grits and conglomerates, which all previous observers had regarded as forming a single group, really include two groups, one of Llandeilo or Arenig, the other of Bala age.

One of the disadvantages, with which a geologist engaged in mapping this district has to contend, is the difficulty of clearly and briefly describing the position of any spot, owing to the small number of names inserted in the 6-inch Ordnance maps, the names of hamlets given being actually fewer than in the 1-inch Geological Survey map. We have, therefore, found it convenient in this paper to distinguish the various streams by the letters B, C, etc.

[1] Geol. Mag. n. s. dec. ii, vol. i (1874) p. 453. A paper on 'Geological Maps & Sections of West Galway & South-West Mayo' by the same author was read at the British Association Meeting at Belfast (1874), but only the title appears in the Report (Trans. Sect. p. 88).

[2] Ann. Rep. Geol. Surv. U. K. for 1896 (1897) pp. 49–50.

[3] Vol. i (1897) pp. 251 *et seqq.*

[4] Proc. Royal Irish Acad. vol. xxvi, sect. B, no. 10 (1907) pp. 129–60.

II. The Sedimentary Rocks and the Tuffs.

As has been already mentioned, thick grits and coarse conglomerates bound the whole district on the west, and play also a prominent part in its southern portion near Tourmakeady; except for them, however, the non-igneous rocks are but poorly exposed. The district is noteworthy for the bad preservation and scanty character of the fossils, a fact which adds greatly to the difficulty of understanding its structure.

(*a*) The Arenig Rocks (Mount Partry Beds).

Scattered throughout the district, especially near its eastern border, are a number of exposures of conglomerate, coarse grit, radiolarian chert, and slate, sometimes associated with interbedded tuff. The grits and cherts are often mentioned in the Survey Memoir,[1] the cherts, which are referred to as 'jasperized shales or hornstones,' being recognized by the authors of the memoir,[2] and by Mr. Kilroe & Sir Archibald Geikie,[3] as the oldest rocks in the district. The coarse conglomerate was, however, regarded as of much later date than the grits and cherts, being grouped, with that exposed all along the western border of the area, as Llandovery by the authors of the Survey Memoir, and as Bala by Sir Archibald Geikie & Mr. Kilroe. Mr. Kilroe[4] has, however, recently come to the conclusion that the apparent succession is the true one, and that this eastern conglomerate is of the same general age as the slates and cherts with which it is associated, while that exposed along the western border is of far more recent date (Bala).

The two conglomerates contrast somewhat strongly as regards the nature of their pebbles: in that exposed along the western border the pebbles are mainly of granite and felsite; while in that associated with the cherts and slates in the south-eastern part of the area, though occasional pebbles of felsite and quartz and rather more numerous pebbles of gneiss and mica-schist occur, grit-pebbles vastly preponderate. This is one of the reasons which leads us to accept Mr. Kilroe's conclusion as to the age of the conglomerate associated with the slaty and cherty series. The resemblance of the cherts to those of Arenig age in the Ballantrae district is extremely close.

The general dip of these beds is in a north-westerly or north-north-westerly direction, which is the usual dip of most of the rocks in this district, and there is frequent evidence of disturbance near the exposures of cherts and slates.

[1] Explan. of Sheets 73 & 74 (in part), 83 & 84, Mem. Geol. Surv. Irel. 1876, pp. 21, 61, 62, 65.
[2] *Ibid.* p. 21.
[3] Ann. Rep. Geol. Surv. U. K. for 1896 (1897) p. 49.
[4] Proc. Roy. Irish Acad. vol. xxvi, sect. B, no. 10 (1907) p. 130 & footnote 1.

Kinahan & Symes,[1] and after them Mr. Kilroe,[2] detected the presence of graptolites in this series, Mr. Kilroe finding in the stream west of the Monastery, Tourmakeady, 'black shales with Lower Llandeilo, or perhaps even Arenig graptolites.' This observation, it will be seen, we have fully confirmed.

The following are the principal exposures of these rocks:—

(1) In the stream close to Tourmakeady Lodge.—In the lower part of the stream south-east of the Lodge (outside the area of our map) the coarse conglomerates are finely exposed, and are apparently overlain by the fine grits, slates, and cherts. The actual junction is not clearly seen, but there is no evidence that it is a faulted one, and the beds close above the conglomerate have the usual north-westerly dip. Slightly higher up the stream the cherts show a certain amount of disturbance, and north-north-east of the Lodge the series includes a few thin bands of tuff. A small intrusion of felsite separates the Arenig Series from the (?)Bala conglomerate which is seen at the bridge north of Tourmakeady Lodge. A small patch of tuff occurs in a field about 300 yards east-north-east of that house.

No fossils have as yet been found in the slates, despite careful search; but microscopical examination of the cherts reveals the presence of rounded bodies, some of which have an inner ring concentric with the circumference, and these are strongly suggestive of casts of radiolaria. Sponge-spicules are fairly common, and Dr. Hinde suggests that a group of minute claw-shaped bodies is made up of denticles from the radulæ of some gasteropod. This chert is derived rather from the silica of sponge-spicules than from radiolaria.

(2) In the Mount Partry neighbourhood.—This area stretches for a mile in a north-easterly direction, from the road leading westwards from the hotel. By far the best section occurs in the bed of the Treanlaur stream (Stream C); it is, in descending order, as follows:—

[See also fig. 1, p. 108.]

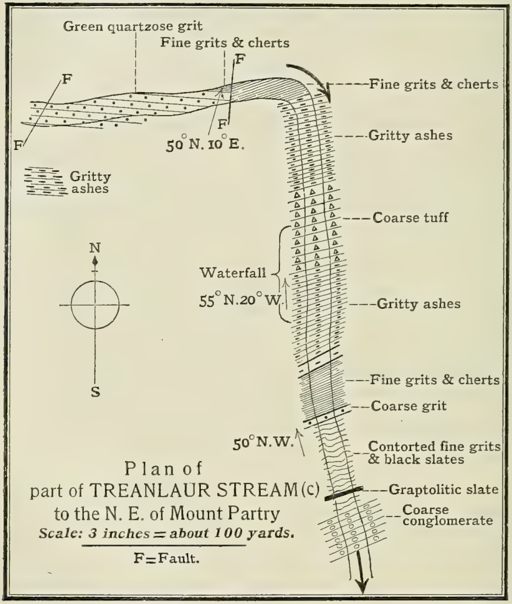
		Thickness in feet.
7. Coarse green grit, very quartzose and felspathic.		
6. Fine grits and cherts	about	20 seen.
5. Fine gritty tuffs		60
4. Coarse tuff		50
3. Fine gritty tuffs		60
2. Fine grits, cherts, and slates, including a black band full of graptolites at about 20 feet above the base		50
1. Coarse conglomerate, thickness seen very considerable: assuming the dip to be constant, it would be about		850

This stream-section is the finest exposure of the Arenig rocks in the district, and differs from that in the Tourmakeady stream

[1] Mem. Geol. Surv. Irel. Sheets 73, 74 (in part), 83 & 84 (1876) pp. 27 *et seqq.*
[2] Ann. Rep. Geol. Surv. U. K. for 1896 (1897) p. 49.

in the far greater development of tuffs and coarse grits. The conglomerate, which is finely exposed, is identical in character with that in the Tourmakeady stream.

Fig. 1. (*For description, see p. 107.*)



The graptolites found in Band 2 have been kindly identified by Miss G. L. Elles, D.Sc., to whom we tender our most sincere thanks; they show that the rocks are of Upper Arenig age (about the zone of *Didymograptus hirundo*), and include the following species:—

Didymograptus acutidens, Elles & Wood (common).
Didymograptus bifidus, Hall (common).
Didymograptus extensus, Hall (common).
Didymograptus filiformis, Tullberg.
Didymograptus gracilis, Törnquist (common).
Didymograptus hirundo, Salt.
Tetragraptus bigsbyi, Hall (1 specimen).
Tetragraptus pendens, Elles.
Tetragraptus, sp. nov. (common).
Diplograptus (Glyptograptus) dentatus (Brongn.).
Clonograptus lapworthi, Rued.
Dendrograptid.

The cherts are exposed, not only in the stream but in a field-drain south of Mount Partry, and in the road north-north-west of St. Mary's Monastery.

The coarse tuff, although only some 50 feet thick in the stream, broadens out on both sides, and forms the hill of Mount Partry and that to the north-west of the Monastery. The bed passes, in places, into a coarse breccia, with large angular blocks of felsite lying in a matrix of an ashy type. This deposit at each locality is suggestive of a vent; but, as it appears to be regularly interbedded among finer tuffs, we hesitate to claim it as such.

The upper band of fine grits and cherts (Band 6) is seen again close to the point where the Mount Partry road branches off, about a third of a mile to the north-west of the hotel; while the coarse grits (Band 7) are well exposed in a road-cutting close by, where they contain small blocks of felsite and chert. The latter rocks are also exposed to the north of the wide strip of coarse ashes east of the Treanlaur stream. Along the whole of its north-western boundary this coarse grit appears to be in contact with felsite, though the junction, even in the Treanlaur stream, is never actually seen.

(3) In the district between Gortanalderg and Drumcoggy Rectory.—The coarse conglomerate occurs in stream D about half a mile south of Drumcoggy Rectory, but no cherts or slates are seen there. Another patch of the conglomerate is seen near the eastern end of the east-and-west road, which crosses the area described in this paper a short distance south of the Rectory. The coarse conglomerate is not met with to the north of this point.

Commencing about half a mile east-north-east of Gortanalderg is a large exposure of the Arenig rocks, forming a roughly triangular area and having a length from south-west to north-east of about 400 yards. The rocks, though considerably disturbed, retain in the main the prevalent north-westerly dip, and appear to be entirely surrounded by felsite, which is faulted against the cherty series on the north-east and south-east sides, and is seen resting upon them along part of the western border.

The lowest beds seen are black slates and cherts, and then, after a gap, comes a considerable exposure of black and red cherts interbedded with coarse quartzose and felspathic grits. All these beds are contorted, and recall most vividly the Arenig cherts of the Ballantrae district.

When the series is followed in the direction of dip, that is, north-westwards, exposures of black chert and fine grit are found to alternate, the whole series being subsequently overlain by coarse quartzose grits closely resembling those of the Mount Partry and St. Mary's Monastery region.

The northern end of the triangle is occupied by a somewhat variable series of grits and tuffs.

Fig. 2.—*Section extending west-north-westwards from St. Mary's Monastery.* (*Horizontal scale : 6 inches = 1 mile.*)
[Section 1 on the map, Pl. IV.]

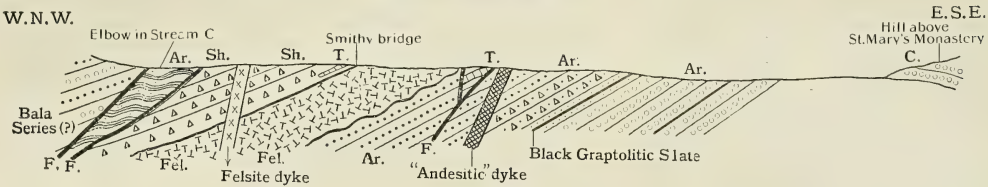
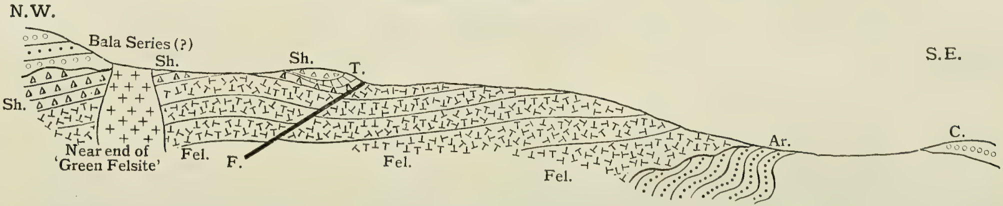


Fig. 3.—*Section a quarter of a mile north of Drumcoggy Rectory.* (*Horizontal scale : 6 inches = 1 mile.*)
[Section 2 on the map, Pl. IV.]



Sh = Shangort Beds (Llandeilo).
T = Tourmakeady Beds (Llandeilo).
Ar = Mount Partry Beds (Arenig).
Fel = Contemporaneous felsite.
C = Carboniferous beds.
F F = Faults.

(4) In the upper part of Stream C, where to the west of Gortanalderg it follows a north-and-south course. —Here a small thickness of radiolarian cherts, black slates, and fine grits is seen dipping north 25° west, and is overlain by a little quartzose grit. The black slates have yielded *Diplograptus (Glyptograptus) dentatus*, Brongn., and small brachiopods (*Pholidops* sp. and *Orbiculoidea ?*). The cherts from this locality are very pure, black, siliceous rocks, breaking with an excellent conchoidal fracture. It is in them that we have found the best-preserved radiolaria in the district, drawings, of some of these being reproduced in fig. 4, p. 112. Unfortunately, the specimens are too imperfect to allow of proper determination. Nearly all seem to consist of three concentric spheres, and show a single radial spine: but Dr. Hinde thinks it very probable that they were furnished with more spines originally. In one specimen no radial spine is shown, and there are several spokes connecting the different spheres. This specimen Dr. Hinde feels inclined to refer to the genus *Rhodosphæra*, Hæckel, while the form with three concentric spheres bears some resemblance to *Spongosphæra tritestacea*, Rothpletz,[1] from the Silurian of Langenstriegis, in Saxony. Sponge-spicules are present in this chert, but they are few in comparison with the abundant radiolaria, and the rock is a genuine radiolarian chert (see Pl. V, fig. 6).

The grits and cherts show signs of much disturbance, and a little higher up the stream the main mass of (?) Bala grits occurring to the west is faulted against them, the line of crush being well seen in the stream-banks.

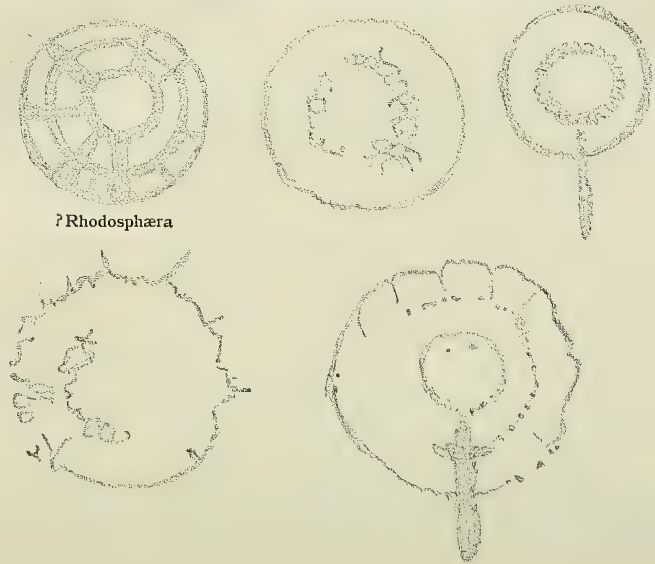
(5) Half a mile west of Drumcoggy Rectory.—Separated from the area No. 3 by red felsite is a small patch of green quartzose grits associated with cherts. The rocks at this spot have the usual strike, and the only point requiring special comment is that coarse grits are here seen underlying the cherts instead of overlying them.

(6) Half a mile north-west of Drumcoggy Rectory.— Here occurs another small area of cherts, having a length of about 300 yards. The cherts are (as usual) red and black, are associated with bands of grit, and though as a rule considerably disturbed, retain the prevalent north-westerly dip. The felsite along the south-western border shows crushing.

(7) Near Gortbunacullin Farm Bridge.—Here in the stream is a rather better section than usual of the cherty series, but the cherts are not so thick or so well-marked as at some places. A considerable thickness of grit is seen both overlying and underlying them. A small patch of tuff, presumably belonging to the Arenig Series, was noted on the eastern border of the felsite about 300 yards north of the bridge.

[1] Zeitschr. Deutsch. Geol. Gesellsch. vol. xxxii (1880) p. 449.

Fig. 4.—*Sketches, by Dr. G. J. Hinde, of radiolaria from the cherts of the upper part of Stream C, west of Gortanalderg, Tourmakeady. (Magnified 200 diameters.)* *See p. 111.*



(8) In the area extending from Gortbunacullin to a point south-west of Shangort.—This is by far the most extensive tract of Arenig rocks, the exposures being met with over an area having a length of about a mile and a half, and showing an uninterrupted strike of about a mile.

Along the whole length of this tract the gritty and cherty rocks are cut off on the west by the great green felsite-intrusion, while their whole eastern boundary appears to be faulted, and the continuity of the exposures is further broken up by smaller felsite-intrusions. Coarse grits, sometimes associated with cherts, are seen at many points in the neighbourhood of Gortbunacullin, and at one point become conglomeratic; but the most instructive section of these rocks is seen in the bed of Stream G, which, after cutting its way through the great green felsite-mass, and through the grits and one of the minor felsite-intrusions, turns north-north-eastwards and for some distance follows the fault bounding the grits on the east. In the stream-section the lowest beds are coarse, green, quartzose grits, and these are overlain by fine grits with chert-bands. Grits, slates, and cherts, in this case underlying, not overlying, coarse grits, can be traced more or less continuously northwards from Stream G to a point west of Shangort, that is, for a distance of about three-quarters of a mile. At one point only have we found any fossils in this exposure of the Arenig Series, namely about a third of a mile south-west of Shangort, where the track from the hamlet crosses the stream: here *Diplograptus (Glyptograptus) dentatus*, Brongn., was found in slate.

The thick series of coarse grits overlying the cherts is finely exposed in a prominent scarp, probably produced in former times by Stream G. The scarp does not follow the outcrop of any particular bed, but, commencing on the south in the green felsite, continues in the coarse grits and a minor felsite-intrusion, ending eventually in more grits at a point west of Shangort. At the southern end of the scarp the coarse grits do not differ in any marked respect from exposures of these rocks elsewhere in the area; but, as one approaches Shangort the beds become much disturbed, the underlying fine grits and slates being broken up and contorted, and blocks of them being embedded in the coarse grit, which farther on becomes conglomeratic, containing well-rounded blocks of felsite, sometimes as much as 2 feet long. These disturbed strata have a thickness of about 30 feet, and pass up into the ordinary quartzose grits. It is probably to this bed that Sir Archibald Geikie refers when he writes [1]:—

> 'Near Shangort I noticed in one of these breccias one block measuring 12 feet, another 20 feet in length and 3 or 4 feet thick, composed of alternating bands of grit and slate.'

Sir Archibald regards the rock to which he refers as a volcanic

[1] 'Ancient Volcanoes of Great Britain' vol. i (1897) p. 253.

Fig. 5.—*Section south of Shangort, passing nearly through the middle of the green felsite-mass. (Section 3 on the map, Pl. IV.)*

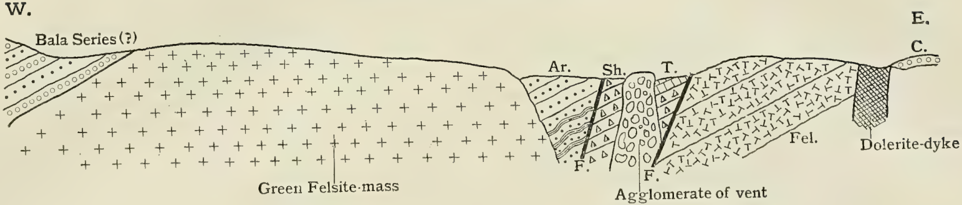
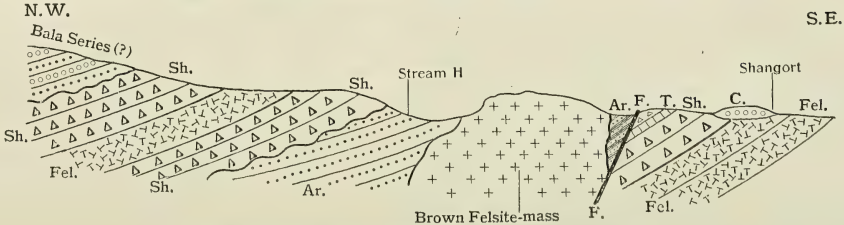


Fig. 6.—*Section north-westwards from Shangort. (Section 4 on the map, Pl. IV.)*



[In both sections the horizontal scale is 6 inches to the mile.]

Sh = Shangort Beds (Llandeilo). Ar = Mount Partry Beds (Arenig). C = Carboniferous beds.
T = Tourmakeady Beds (Llandeilo). Fel = Contemporaneous felsite. F F = Faults.

breccia. We are inclined to think that the rock which we have just described is a fault-breccia, for the following reasons :—

(*a*) It occurs close to the line of fault separating the coarse Arenig grits dipping west 10° south from the Llandeilo tuffs on the east, which dip about north-westwards.

(*b*) The underlying fine grits show extensive rupture and displacement just where the breccia is seen, and resemble exactly the masses of grit and slate included in the breccia.

(*c*) The matrix of the breccia is quartzose and gritty, closely resembling the grits on the west.

(9) The Shangort and Derrassa area.—We believe that this area is separated by a fault from that just described. The outcrop of the gritty and cherty series widens considerably in the neighbourhood of Derrassa, where the rocks are seen striking up against the green felsite-intrusion, and are almost bisected by a southward-projecting tongue of red felsite. At the north-eastern end of the outcrop in Stream H, the Carboniferous conglomerate is seen resting directly upon the grits.

A strip of chert, having a probable width of only some 30 or 40 yards, can be traced for nearly 500 yards along the south-eastern border of the brown felsite-mass north-west of Shangort.

(*b*) The Llandeilo Rocks.

It may, perhaps, be desirable to state succinctly at the commencement of our description of the Llandeilo rocks that although, for the sake of convenience, we divide them into two groups, a gritty and ashy series and a calcareous series, and apply the name of Shangort Beds to the former, and of Tourmakeady Beds to the latter, yet the two groups are intimately associated, and we consider them to be of the same general geological age.

(b_1) The main gritty and ashy series (Shangort Beds).

In addition to the tuffs which we have already described when dealing with the Arenig rocks, others are continually met with throughout the whole district. West of the great red felsite-mass they occupy an irregular strip extending from near Tourmakeady Lodge to Shangort, and then, after a break in their continuity, they are again seen in the neighbourhood of Derrindaffderg. While some of these rocks are normal tuffs with little non-igneous matter, the great majority contain a large proportion of gritty material. Every gradation may be traced, from a pure grit through an ashy grit and a gritty tuff, to a tuff almost entirely free from non-igneous matter. They vary, too, greatly in coarseness, some being very fine tuffs, others very coarse breccias, which may contain large or small blocks of limestone.

When unweathered, these gritty tuffs are very hard, and appear to be almost, if not entirely, unfossiliferous. They readily weather,

however, into a crumbly brown rock resembling a soft sandstone, and traces of fossils, generally in a very poor state of preservation, can then nearly always be found in them. At certain localities near Gortbunacullin a considerable series of fossils was obtained, which clearly proved the deposit to be of Llandeilo age.

For descriptive purposes the district may be subdivided as follows:—

(1) The area west of the Tourmakeady-Drumcoggy red felsite.—This area, which has a length of about 2 miles, is bounded on the west by the coarse (?) Bala conglomerate, the boundary being traceable with fair regularity and continuity. On the east it is bounded by the red felsite, and the boundary is most irregular and sinuous. The ashy rocks are not well exposed, and their principal interest lies in their association with the peculiar patches of limestone-breccia which we describe in the sequel. A series of small intrusions of felsite, andesitic rock, and hornblende-lamprophyre pierce the tuffs. Between the Bohaun road and Stream C are several exposures of tuffs, coarse and fine, striking in the normal north-north-easterly direction, but they do not merit a detailed description. The gritty tuffs which are so prevalent farther north at Gortbunacullin are first met with in a low bank by the Smithy bridge, where they have yielded the following fossils in a very poor state of preservation:—*Plectambonites sericea*, Sow., *Pl. quinquecostata*, M'Coy, *Orthis elegantula*, Dalm., *Scenidium* sp., *Cybele connemarica*, sp. nov.

Some 200 yards up the stream an *Illænus* was found in calcareous grit. The Llandeilo grits lie east of the angle made by Stream C, and are separated from the Bala grits and conglomerates on the west by a narrow area of Arenig slates and cherts which show much faulting, the stream for a time following the Arenig band. Gritty tuffs are exposed at various points in the moorland north-east of Gortanalderg, but no section of these rocks is met with until one reaches the east-and-west road which joins the main road south of Drumcoggy Rectory. Here is a fairly good section of tuffs, variable in character, which at a point (293)[1] just south of the road yielded the following fossils:—*Plectambonites sericea*, Sow., *Pl. quinquecostata*, M'Coy, *Orthis* sp., *Illænus* sp., *Cyphaspis* sp., and *Pliomera* cf. *barrandei*, Billings.

(2) The area between Stream F and the southern part of the green felsite-intrusion.—This is an irregular area, having a length of about a mile and a maximum width of about half a mile. Its north-western boundary is not clearly defined, but we believe that the Llandeilo tuffs are here faulted against the Arenig grits, slates, and cherts. On the east the area is bounded by the red felsite, the junction being very sinuous. Along the

[1] These numerals in parentheses throughout the paper indicate localities, shown in the map (Pl. IV), where fossils or rock-specimens were obtained.

eastern border there is a remarkably fine development of the limestone-breccia, and overlying this a series of coarse breccias, consisting of felsite-blocks embedded in a fine ashy matrix, is exposed at several points.

The prevailing rock-type is, however, the calcareous grit or gritty ash, which, as has been already mentioned, is especially characteristic of the Llandeilo of the district. As elsewhere, the rock when fresh is very hard and compact, and fossils could only be detected when it was much weathered. The following fossils were found a quarter of a mile south of Gortbunacullin (212):—

Camerella sp.	*Phacops (Chasmops)* sp.
Orthisina ascendens, Pander.	*Pliomera benevolens*, Salt. (?).
Orthis crispa, M'Coy (?).	*Pliomera pseudoarticulata*, Portl. (?).
Orthis testudinaria, Dalm.	*Helicotoma* or *Euomphalus* sp.
Orthis sp.	Crinoids.
Acidaspis sp.	*Glyptocystis (?)* sp.
Cybele connemarica, sp. nov.	Monticuliporoid.
Encrinurus sp.	

At a spot about a third of a mile south-south-west of Gortbunacullin, and near a little patch of limestone-breccia, the following fossils occurred in calcareous grit (318):—*Plectambonites sericea*, Sow. (?), *Orthis* cf. *intercostata*, Portl., *Orthis* sp., *Triplecia spiriferoides*, Portl., *Orthis* cf. *christianiæ*, Kjerulf, crinoids, and *Asaphus* sp.

(3) The district lying east of the main part of the green felsite-intrusion.—This district, which is on the line of strike of that just described, and only separated from it by a short space, has a length of rather over half a mile and a width of, as a rule, 200 yards or less.

In the southern part a large series of fossils was obtained from ashy grits of the same type as those found near Gortbunacullin. Mr. Reed has identified those enumerated in the following list from a point (322) about half a mile south-south-west of Shangort. The presence of *Pliomera (= Amphion)*, which occurs in some abundance, definitely fixes the age of the beds as not later than Llandeilo.

Camerella thomsoni, Dav.	*Calymene* sp.
Orbiculoidea sp.	*Cybele connemarica*, sp. nov.
Orthisina ascendens, Pander (?).	*Encrinurus* cf. *multisegmentatus*, Portl.
Orthis cf. *actoniæ*, Sow.	*Illænus* sp.
Orthis calligramma, Dalm.	*Lichas* sp.
Orthis crispa, M'Coy (?).	*Pliomera benevolens*, Salt. (?).
Orthis cf. *interplicata*, M'Coy.	*Pliomera* cf. *pseudoarticulata*, Portl.
Orthis testudinaria, Dalm.	*Sphærocoryphe* sp.
Orthis sp.	*Turrilepas* sp.
Plectambonites sericea, Sow.	*Eccyliomphalus* sp.
Streptis affinis, sp. nov.	Indeterminable gasteropod.
Apatocephalus (?) sp.	*Glyptocystis (?)* sp.
Asaphus sp.	
Symphysurus (?) sp.	

Farther north a similar series of ashy grits is met with, in which, at a point (217) about 300 yards south-west of Shangort, the

following fossils were found:—*Cheirurus* sp., *Orthis testudinaria*, Dalm., *Orthis* sp., *Plectambonites sericea*, Sow. (?), *Leptæna* cf. *llandeiloensis*, Dav., and *Acrotreta (?) hibernica*, sp. nov.

A patch of limestone-breccia and a mass of compact limestone occur in association with these rocks, the compact limestone being bounded on the west by a mass of coarse breccia which probably represents a vent. To this we shall refer subsequently.

(4) The district lying north-west of Shangort.—A strip of Llandeilo ashy rocks, overlapped on the west by the coarse (?) Bala conglomerate, extends in a north-easterly direction from Stream H to Derrindaffderg, a distance of about three-quarters of a mile; and a second strip, separated from the first (except at the northern end) by a long tongue of red felsite, lies farther east. The ashy series met with in this region does not include examples of the gritty beds which have yielded fossils on the south, but consists entirely of definite tuffs, which sometimes, especially in the southern part near Stream H, are very coarse. The felsite that separates the two strips of tuff sometimes contains xenoliths; and it is by no means easy to discriminate in the field between it and some of the tuffs.

(b_2) The Calcareous Series (Tourmakeady Beds).

Along the western side of the area, from a point about 300 yards north-east of Tourmakeady Lodge to Gortbunacullin Farm bridge, are numerous exposures in a very remarkable deposit of a calcareous nature. As will be seen by reference to the map (Pl. IV), the deposit is far from being continuous; at certain places it has obviously been broken up by earth-movements, but there seems no reason to suppose that the bed originally formed a continuous deposit between the various spots where it is now found.

The calcareous rocks show three different lithological types:—

(1) Compact bedded limestone.—This is rarely seen.

(2) Limestone brecciated in place.—This is only occasionally met with, the commonest type of calcareous deposit being

(3) Limestone-breccia; and if this is, as we believe, a deposit produced by volcanic explosions, it is easy to understand how it might be formed in disconnected patches on the floor of the sea near the vent or vents through which it was ejected.

Some further details regarding these three types of calcareous deposit may now be given:—

(1) Compact bedded limestone.—This is red, pink, or grey in colour, and contains in some places quartz-grains which near Shangort become so numerous that the rock passes into a calcareous sandstone.

(2) Limestone brecciated in place.—This is a pink or white rock, which, after being cracked into numberless pieces, has been

recemented by the deposition of material in the cracks. This type of limestone, which has not yielded any fossils, contains, occasionally, scattered angular masses of red or green chert.

(3) Limestone-breccia.—Two main types of these rocks seem to be recognizable:—

(*a*) A coarse type which contains angular blocks of limestone, red, pink, or grey in colour and horny or crystalline in texture, intermingled with angular blocks of red and green felsite. The matrix in which these blocks are embedded is generally in a very much weathered state, but, when fresh, is found to be a calcareous ashy grit, closely resembling that in which near Gortbunacullin and elsewhere Llandeilo fossils have been found. The blocks measure occasionally as much as 18 inches across, but more usually about 4 or 6 inches. We have found no fossils in the matrix, although some of the included limestone-blocks have yielded a rich harvest of fossils.

(*b*) A finer type showing often a distinct stratification, and consisting principally of small pieces of limestone of various sizes up to 1 inch across, and of less numerous fragments of felsite and red chert, embedded in a relatively scanty matrix of the nature of a calcareous grit.

Description of the exposures of the Tourmakeady Beds.—(1) The southernmost exposure is about 300 yards north-east of Tourmakeady Lodge. It is in a wood, and the relations of the rock to the surrounding beds are entirely obscured. Both the types of breccia are seen here.

(2) Immediately west of the Smithy bridge are several small exposures of coarse and fine breccia, perhaps parts of a continuous strip.

(3) Some 200 yards east-south-east of the same bridge is a small patch of limestone-breccia, closely associated with a breccia composed of felsite. This is the only exposure of the calcareous series seen on the eastern side of the red felsite.

(4) South of Gortanalderg is a patch of limestone-breccia of the coarse type, and associated with it is a breccia formed of felsite-fragments. The occurrence of crushed material on the north points to the presence of a fault separating it from the felsite.

(5) About 300 yards south-east of the last-described exposure is a small one, showing both coarse and fine types of limestone-breccia, with fine gritty ashes immediately beneath. The limestone fragments are of various sizes up to 4 inches across. Small felsite-fragments are also very numerous.

(6) West of Gortanalderg a strip of limestone, about 400 yards long, extends from the stream through some fields as far as the road coming from the village. The rock here is not a breccia formed of limestone-fragments embedded in a more or less ashy matrix, but a well-bedded grey and pink limestone, which, though often much

Fig. 7.—*Limestone-breccia near (45), upper part of Stream F.* *See p. 121.*

Fig. 8.—*Limestone-breccia near (45), upper part of Stream F.* *See p. 121.*

brecciated, is entirely free from admixture with ashy material. It dips north 30° west, and has a thickness of at least 30 feet. It appears to be regularly interbedded in grit. The (?) Bala grits and conglomerates are seen faulted against it in the stream.

(7) About 500 yards north-east of Gortanalderg is a strip of limestone-breccia about 100 yards long. This is of the coarse type, and contains many felsite-fragments. It appears to be interbedded with gritty ashes.

We now come to a set of exposures of much more continuous character, seen along the course of Stream F:—

(8) Four patches form a nearly continuous band, which can be traced for 300 yards or more. It clearly follows the strike of the associated tuffs, which at one point dip northwards at 40°. The limestone-breccia is identical in character with the coarse type described above, and consists of blocks of limestone and of felsite embedded in a matrix which weathers very readily into a perfectly rotten rock, but when fresh is seen to be a calcareous ashy grit, practically identical in character with the fossiliferous rock at Gortbunacullin and elsewhere. The limestone-blocks are, as a rule, of a horny type and white or grey, but there are a few red crystalline blocks, including one having a length of 2 feet. From these blocks, and chiefly from the large one just mentioned, we collected the following fossils (45):—

Acrotreta (?) hibernica, sp. nov.
Camerella thomsoni, Dav. (?).
Lingula brevis, Portl.
Lingula ovata, M'Coy.
Orthis calligramma, Dalm.
Orthis elegantula, Dalm.
Orthis sp.
Plectambonites sericea, Sow.
Porambonites cf. *intercedens*, Pander.
Porambonites sp.
Strophomena antiquata, Sow.
Strophomena cf. *retroflexa*, Salt.
Acidaspis aff. *bispinosus*, M'Coy.
Agnostus agnostiformis, M'Coy.
Cheirurus sp.
Harpes sp.
Illænus bowmani, Salt. (?).
Illænus sp. aff. *chudleighensis*, Holm.
Illænus sp.
Pliomera pseudoarticulata, Portl.
Pliomera aff. *fischeri*, Eichw.
Sphærocoryphe sp.
Primitia sp.
Turrilepas sp.
Crinoids.

At one spot on the northern bank is an exposure showing several huge blocks of limestone, one of which measures 10 by 6 feet. This rock is grey and unfossiliferous, but contains numerous quartz-grains. Three other considerable exposures of limestone-breccia are met with before the point where the stream, on meeting the road from Gortbunacullin, bends sharply south-eastwards. They are all of the coarse type, and call for no special description. East of this bend of the stream, however, occurs a narrow strip, trending north by east, which crosses the stream, and can be followed for a distance of nearly 300 yards. It is exposed at several points south of the stream and in the stream-bed itself, but the best exposures are in some small excavations on the north. Here the deposit consists of an upper mass of breccia of the usual coarse type, but

stained in places with copper carbonate, and a lower compact limestone, which sometimes contains quartz-grains and is occasionally much crushed. The limestone-breccia rests regularly, without any sign of break, upon the compact limestone, of which a thickness of about 8 feet is seen.

Fig. 9.—*Limestone-breccia (58), lower part of Stream F.*

The following series of fossils was obtained from blocks in the breccia exposed in the stream, and in a small excavation north of the stream (58):—

Orthis sp.
Plectambonites sericea, Sow.
Lingula brevis, Portl. (?).
Illænus weaveri, sp. nov.
Cheirurus aff. *ingricus*, Schmidt.
Telephus hibernicus, sp. nov.

(9) Completely off the strike of these exposures is a small patch of limestone-breccia, lying about a third of a mile south-west of Gortbunacullin. The breccia is of the coarse type, and presents no unusual features.

(10) The northernmost exposures of the calcareous series are two lying respectively south-west and north-west of Shangort.

South-west of Shangort is a mass of compact limestone, having a probable thickness of not less than 40 feet and a length of about 100 yards. This mass (88), which is exposed in a rather large quarry, is faulted against red felsite on the east. Very small patches of Carboniferous conglomerate are seen in the quarry resting upon both rocks. Lithologically the limestone is hard, compact, and horny, usually grey but sometimes pink. It frequently has small quartz-grains thickly scattered through it, and may be said to pass in places into a calcareous sandstone. Here and there patches of red chert occur in the limestone. Fossils are very scanty; several hours' search yielded only one *Orthis simplex*, M'Coy, a fragment of *Harpes*, and a crinoid-joint.

North-west of Shangort is a strip of limestone-breccia having a length of about 150 yards, and trending in a north-easterly direction along the course of a small tributary of Stream H. The matrix of the breccia is the usual type of gritty ash, and the fragments seem to be exclusively of limestone, no felsite having been found.

As the fossiliferous limestone generally occurs in the form of dislocated blocks, the deposit as a whole was originally regarded by the officers of the Geological Survey as of 'Upper Silurian' age, the blocks being considered derivative: but Sir Archibald Geikie & Mr. Kilroe (Ann. Rep. Geol. Surv. for 1896, p. 49)

'obtained clear evidence that the limestone is truly interstratified in the volcanic series; that the fossils it contains are not derivative, but belong to the time of deposition of the limestone, and that the same organisms occur in the calcareous tuffs associated with the limestone.'

Sir Archibald Geikie writes as follows with regard to the calcareous beds found in the Tourmakeady, Glensaul, and Lough Nafooey districts ('Anc. Volc. Gr. Brit.' vol. i, 1897, p. 252):—

'The rocks in each of these three areas are similar. One of their distinguishing features is the intercalation among them of a fossiliferous limestone and calcareous fossiliferous tuffs, which contain well-preserved species of organisms characteristic of the Bala division of the Lower Silurian rocks. There cannot be any question that these organisms were living at the time the strata in which their remains occur are found [*sic*].* The most delicate parts of the sculpture on *Illænus Bowmanni* and *Orthis elegantula* are well preserved. Nor have the limestones been pushed into their present places by volcanic agency, or by faults in the terrestrial crust. They are not only regularly intercalated among the volcanic rocks, but the limestone in some places abounds in volcanic dust, while above it come calcareous tuffs, also containing the same fossils. It is thus clearly established that the volcanic series ...... has its geological age definitely fixed as that of the Bala period.'

[* (?) Misprint for 'were formed.']

With regard to the age of the limestone, Mr. Reed is convinced by the fossil evidence that it is not of Bala, but of Llandeilo age. The reasons for this view are set forth in the appendix to this paper. Further, in the passage quoted above, Sir Archibald Geikie appears to imply that all the limestones lie associated with the tuffs approximately as they were originally deposited. This is no doubt the case with regard to the compact bedded limestones, but it appears to us impossible to maintain this view as regards the rocks which

we have described as limestone-breccias. In the great majority of cases the limestone undoubtedly occurs in the form of disrupted blocks embedded in a calcareous ashy matrix. It seems impossible to avoid the conclusion that, after the deposition of the fossiliferous limestone, it was in some places broken up by volcanic eruptions, and the fragments, accompanied by fragments of felsite, were embedded in a tuff which must thus be of later date than the limestone. It does not, however, follow that there was any very great interval of time between the deposition of the limestone and its disruption, succeeded by the embedding of its fragments in a coarse tuff. The character of the fossils shows that both original deposition and redeposition after disruption took place during Llandeilo times. The view of the explosive origin of the limestone-breccia affords an adequate explanation of its patchy method of occurrence.

(*c*) List of Fossils from the Llandeilo Beds.	Shangort Beds. (Gritty and Ashy Series.)						Tourmakeady Beds. (Calcareous Series.)		
	Smithy bridge. (5)	$\frac{1}{4}$ mile south of Gortbunacullin. (212)	$\frac{1}{8}$ mile south-south-west of Shangort. (322)	300 yards south-west of Shangort. (217)	1 mile west of Drumcoggy Rectory. (293)	$\frac{1}{3}$ mile south-west of Gortbunacullin. (318)	Upper part of Stream F, 1 mile south-west of Gortbunacullin Farm bridge. (45)	Stream F, 100 yards west of Gortbunacullin Farm. (58)	300 yards south-south-west of Shangort. (88)
Acrotreta (?) hibernica, sp. nov.	...	...	...	+	...	...	+	...	...
Camerella thomsoni, Dav.	...	...	+	...	...	...	+	...	...
Camerella (?) sp.	...	+	...	...	...	...	...	...	...
Cf. *Leptæna llandeiloensis*, Dav.	...	...	...	+	...	...	...	...	...
Lingula brevis, Portl. (?)	...	...	...	...	...	...	+	+	...
Lingula ovata, M'Coy	...	...	...	...	...	...	+	...	...
Orbiculoidea sp.	...	...	+	...	...	...	...	...	...
Orthis cf. *actoniæ*, Sow.	...	...	+	...	...	...	...	...	...
Orthis calligramma, Dalm.	...	...	+	...	...	...	+	...	...
Orthis cf. *christianiæ*, Kjer.	...	...	...	...	...	+	...	...	...
Orthis crispa, M'Coy (?)	...	+	+	...	...	...	...	...	...
Orthis elegantula, Dalm.	+	...	...	...	...	...	+	...	...
Orthis cf. *intercostata*, Portl.	...	...	...	...	...	+	...	...	...
Orthis cf. *interplicata*, M'Coy	...	...	+	...	...	...	...	...	...
Orthis simplex, M'Coy	...	...	...	...	...	...	...	...	+
Orthis testudinaria, Dalm. (?)	...	+	+	+	...	...	...	...	...
Orthis sp. indet.	+	+	+	+	+	+	+	+	...
Orthisina ascendens, Pander	...	+	+?	...	...	...	...	...	...
Plectambonites quinquecostata, M'Coy	+	...	...	...	+	...	...	...	...
Plectambonites sericea, Sow.	+	...	+	+	+	+?	+	+	...
Porambonites cf. *intercedens*, Pander	...	...	...	...	...	...	+	...	...
Porambonites sp.	...	...	+	...	...	...	+	...	...
Scenidium (?) sp.	+	...	...	...	...	...	...	...	...
Streptis affinis, sp. nov.	...	...	+	...	...	...	...	...	...

List of Fossils (*continued*).	Shangort Beds. (Gritty and Ashy Series.) Smithy bridge. (5)	1/4 mile south of Gortbunacullin. (212)	1/3 mile south-south-west of Shangort. (322)	300 yards south-west of Shangort. (217)	1 mile west of Drumcoggy Rectory. (293)	1/3 mile south-west of Gortbunacullin. (318)	Tourmakeady Beds. (Calcareous Series.) Upper part of Stream F, 1 mile south-west of Gortbunacullin Farm bridge. (45)	Stream F, 100 yards west of Gortbunacullin Farm. (58)	300 yards south-south-west of Shangort. (88)
Strophomena antiquata, Sow.	...	...	...	...	...	...	+	...	...
Strophomena cf. *retroflexa*, Salt.	...	...	...	...	...	...	+	...	...
Triplecia spiriferoides, Portl.	...	...	...	...	...	+?	...	...	...
Monticuliporoid	...	+	...	...	...	...	...	...	...
Acidaspis aff. *bispinosus*, M'Coy	...	...	...	...	...	...	+	...	...
Acidaspis (?) sp.	...	+	...	...	...	...	...	...	...
Agnostus agnostiformis, M'Coy	...	...	...	...	...	...	+	...	...
Apatocephalus (?) sp.	...	...	+	...	...	...	...	...	...
Asaphus (?) sp.	...	...	+	...	...	+	...	...	...
Calymene sp.	...	...	+	...	...	...	...	...	...
Cheirurus aff. *ingricus*, Schmidt	...	...	...	...	...	...	...	+	...
Cheirurus sp.	...	...	...	+	...	...	+	...	...
Cybele connemarica, sp. nov.	+?	+	+	...	...	...	...	...	...
Cyphaspis (?) sp.	...	...	...	...	+	...	...	...	...
Encrinurus aff. *multisegmentatus*, Portl.	...	...	+	...	...	...	...	...	...
Encrinurus sp.	...	+	...	...	...	...	...	...	...
Harpes sp.	...	...	...	...	...	...	+	...	+
Illænus bowmani, Salt. (?)	...	...	...	...	...	...	+	...	...
Illænus aff. *chudleighensis*, Holm.	...	...	...	...	...	...	+	...	...
Illænus weaveri, sp. nov.	...	...	...	...	...	...	...	+	...
Illænus sp. indet.	...	...	+	...	+	...	+	...	...
Lichas sp.	...	...	+	...	...	...	...	...	...
Phacops (Chasmops) sp.	...	+	...	...	...	...	...	...	...
Pliomera cf. *barrandei*, Billings	...	...	...	...	+	...	...	...	...
Pliomera benevolens, Salt.	...	+?	+?	...	...	...	...	...	...
Pliomera aff. *fischeri*, Eichw.	...	...	...	...	...	...	+	...	...
Pliomera pseudoarticulata, Portl.	...	+	+	...	...	...	+	...	...
Sphærocoryphe (?) sp.	...	...	+	...	...	...	+	...	...
Symphysurus (?) sp.	...	...	+	...	...	...	...	...	...
Telephus hibernicus, sp. nov.	...	...	...	...	...	...	...	+	...
Primitia sp.	...	...	...	...	...	...	+	...	...
Turrilepas sp.	...	...	+	...	...	...	+	...	...
Glyptocystis (?) sp.	...	+	+	...	...	...	...	...	...
Crinoids	...	+	...	...	...	+	+	...	+
Helicotoma or *Euomphalus* sp.	...	+	...	...	...	...	...	...	...
Eccyliomphalus (?) sp.	...	...	+	...	...	...	...	...	...

(*d*) The (?) Bala Conglomerate and Grit.

The district with which we are dealing is bounded along the whole of its western margin by a great series of conglomerates and grits. We have not been immediately concerned with these

rocks, and propose to refer to them very briefly. In the southern part of the area, especially along the steep road over the hill from Tourmakeady to Bohaun, and in the bed of the stream near which the road runs for some distance, the rocks are finely exposed and consist mainly of very coarse conglomerates. The blocks of these conglomerates may reach a length of a foot or more, and are chiefly red granite and quartz-felsite. Subordinate beds of grit are associated with the conglomerates.

A well-marked conglomerate, with pebbles chiefly of quartz-felsite, rests upon the Llandeilo Beds near Gortanalderg and stretches as far as Stream F, where it passes into grit, this forming the prevalent rock all along the remainder of the western margin of the area. The grit becomes pebbly in places, the pebbles being of felsite or quartz.

Between Streams G and H these grits occur in direct relation to the green felsite, the two rocks being seen in juxtaposition in Stream H; and from this point the grits, which are often pebbly, show a fairly continuous series of exposures as far as Derrindaffderg, where they disappear beneath the quartzose conglomerate and red sandstone of the Carboniferous System. As regards the age of these rocks, it is clear that they are newer than the gritty tuffs and limestones with Llandeilo fossils, and they show no lithological resemblance to the sandstones with Llandovery fossils which occur farther south in the neighbourhood of Trean[1] and at the mouth of the Owenbrin river.[2] We, like all previous observers, have been unable to find any fossils in these rocks in the Tourmakeady district; but Sir Archibald Geikie ('Anc. Volc. Gr. Brit.' vol. i, 1897, p. 253) mentions that in the region farther south-west they include bands with Bala fossils, and we are quite ready to accept his and Mr. Kilroe's conclusions that these conglomerates are of Bala age.

[1] We found here the following fossils in ferruginous grit:—*Favosites hisingeri*, M.-Edw., *Lindstrœmia* sp., *Palæocyclus* sp., *Leptæna rhomboidalis*, Wilck., *Cœlospira hemispherica*, Sow., *Encrinurus punctatus*, Brünn., and *Beyrichia* sp.

[2] We found the following fossils in blocks of ferruginous sandstone on the shore of Lough Mask, west of Black Rock, and north of the mouth of the Owenbrin River:—

Lindstrœmia subduplicata, M'Coy.
Lindstrœmia sp.
Favosites sp.
Crinoids.
Orthis calligramma var. *sowerbyana*, Dav.
Orthis elegantula, Dalm.
Orthis reversa, Salt.
Orthis sp.
Cœlospira hemispherica, Sow.
Rhynchospira baylei, Dav.
Pterinæa squamosa, M'Coy.
Trochonema tricincta, M'Coy.
Cyclonema sp.
Holopea sp.
Pleurotomaria sp.
Conularia sp.
Orthoceras subgregarium, M'Coy.
Orthoceras sp.
Encrinurus punctatus, Brünn.
Phacops aff. *downingiæ*, Murch.
Illænus cf. *macallumi*, Salt.

III. The Field-Relations of the Crystalline Igneous Rocks.

The crystalline rocks include:

(*a*) a great series of felsites, many certainly intrusive, others contemporaneous;

(*b*) a small development of intrusive andesitic rocks;

(*c*) a number of small but interesting intrusions of hornblende-lamprophyre, and dolerite.

(*a*) The Felsites.

The rocks which play the most prominent part in the Tourmakeady district are undoubtedly the felsites. They form a number of relatively small intrusions along the western and south-western borders of the district; but it is in the central part, from near Tourmakeady Lodge to Shangort, that this type of rock is especially prominent, forming nearly all the high ground, and extending with lessening importance as far as the neighbourhood of Derrindaffderg. Lithologically, the rocks belong to three fairly well-marked types:—(α) the green and brown felsite, (β) the red felsite, and (γ) the augite-felsite.

The field-relations of these rocks may now be briefly described.

(α) The green and brown felsite.—This rock-type is characterized partly by the prevailing colour of the ground-mass, but chiefly by the size and prominence of the quartz-phenocrysts. Though it occurs here and there all over the district, its principal development is north-west of a line drawn between Shangort and Gortbunacullin. Here it forms a great oval mass, having a length of about a mile and a maximum width of nearly half a mile, extending from the neighbourhood of Derrassa to Stream G, north-west of Gortbunacullin. South of the stream the mass tapers and becomes more irregular, but extends as far as about half a mile south-west of Gortbunacullin, and therefore the total length of the mass is about a mile and a third. All along its northern and eastern border it truncates the ends of the bedded rocks, tuffs, grits, and cherts, but along its western border its relations to the coarse (?) Bala conglomerate are nowhere visible, owing to the covering of peat, except at certain points in the upper parts of Streams G and H. In the latter stream, however, the felsite shows what appears to be a chilled edge, suggesting that it is an intrusion of later date than the (?) Bala conglomerate. The section is not, however, so clear as could be wished, and can hardly be regarded as conclusive on this point.

North of Gortbunacullin patches of chert are seen caught up by the green felsite, exposed in the bed of Stream G.

The green felsite-mass further gives off, from a point near Gortbunacullin, a long narrow tongue, which stretches north-eastwards through the grits and cherts and can be traced nearly to the western bank of Stream G until cut off by a fault. The total length of this tongue is more than half a mile.

The brown felsite, which is practically identical with the green, the difference of colour being unimportant, forms a patch with a length of about a third of a mile lying north-west of Shangort, and a smaller patch lying east of the green felsite-mass. Brown felsite of similar character to the above also occurs at various points near Tourmakeady and near Gortanalderg.

Intrusive masses of felsite, which agree with the main green felsite as regards both colour and the prominence of the phenocrysts, occur south-west of the district with which this paper deals, only their north-eastern terminations entering it. They form two long narrow tongues, each having a length of over a mile and a width which rarely exceeds 150 yards. The more southerly, commencing near Cappaghduff West, follows the Glensaul river and ends in the Tourmakeady demesne. The more northerly, commencing at a point nearly due west of the termination of the more southerly, extends towards Gortanalderg. It is possible that the two may be parts of the same band shifted by a fault. Neither band makes any prominent surface-feature.

(β) The red felsite.—Though the prevalence of a red colour justifies us in referring to this rock as the red felsite, it is not implied that the redness is an invariable characteristic, the rock often locally becoming brown or green. In the bed of Stream B is seen the southernmost outcrop of the great stretch of red felsite which, except for a brief break in Stream F at Gortbunacullin-Farm bridge, extends continuously to Shangort, a distance of $3\frac{3}{4}$ miles. For the first three-quarters of a mile, from Stream B to Stream C, the red felsite has an outcrop with a fairly uniform width of about 300 yards; but, from Stream C onwards to Stream F, the outcrop becomes very much wider, the maximum width occurring at a point north-west of Drumcoggy Rectory and measuring about 1100 yards. The most remarkable feature about the outcrop is, however, its extraordinarily sinuous character. Along the western margin it repeatedly bends eastward, so that it passes to the east of successive patches of limestone-breccia; while along its eastern border its westward bending, so as to pass to the west of patches of grits and cherts, is almost equally noteworthy. South-west of Drumcoggy Rectory one large patch and several smaller patches of grits, cherts, and tuffs are completely surrounded by it. But, while along this lengthy outcrop it is clearly exposed at many points in the neighbourhood, now of the grits and cherts, now of the coarse tuffs, and now of the limestone-breccia, only at one point have we been able to find it actually in contact with any of these rocks. This point is along the south-western border of the triangular area of

cherts, grits, and tuffs lying about one mile south-west of Drumcoggy Rectory. Here the red felsite is seen resting without any apparent disturbance upon the cherts. Several small isolated patches of felsite occur at intervals west of the main outcrop.

North of Stream F the width of the felsite rapidly narrows. The eastern outcrop from that stream to Shangort follows a fairly straight line, and forms a well-marked scarp overlooking an alluvial area where no exposures except occasional intrusions of dolerite are seen; the western outcrop is more sinuous. At Shangort the felsite is overlapped by the basal Carboniferous conglomerate; but it commences again near Derrassa, and forms an irregular mass extending as far as Derrindaffderg.

(*c*) The augite-felsite.—Although augite has been detected in the felsites at a number of points, only at one spot does this rock form a well-marked and distinctive mass. This is at a point south-south-west of Shangort, where an oval mass of augite-felsite, having a length of about 150 yards, intrudes into the Shangort Beds.

As regards the nature of the various felsites, there can be no doubt that the principal green and brown felsite-masses are intrusive. The massive boss-like character of the green felsite and the way in which it truncates the ends of the coarse Arenig grits south-west of Derrassa clearly point to its intrusive nature. It is, however, noteworthy that little or no sign of metamorphism can be detected round this great mass of felsite, but the type of rock that it penetrates is not one which readily lends itself to metamorphic change.

The two long felsite-tongues south-west of the district described in this paper, and the smaller patches of felsite which occur in the Shangort Beds along the western margin of the main red felsite-mass, are all clearly of an intrusive nature.

It is, however, with regard to the main red felsite-mass, which extends northwards from Tourmakeady stream to near Shangort, that the chief difficulty arises. Its most noteworthy features are:—

(1) The extraordinarily sinuous outcrop.
(2) The remarkable variations in the width of the outcrop, from about 250 yards near Tourmakeady to nearly 1200 yards at a point north of Drumcoggy Rectory.

Along its eastern border it is seen at various points in close relation with the Mount Partry beds of Arenig age, and along its western border with the Llandeilo grits and tuffs. Only at two spots, one near Gortbunacullin Farmhouse, and a second at a point near the south-western end of the triangular area of Arenig Beds, 1 mile west-south-west of Drumcoggy Rectory, have we found it in actual contact with any other rock, and at both these spots it rests upon the Arenig cherty series. It is nowhere seen in relation to the coarse (?) Bala conglomerate.

The following are the possibilities with regard to the red felsite :—

1. That it may be intrusive either (*a*) as a boss like the green felsite, forcing its way indifferently through all the pre-Bala sedimentary rocks, or (*b*) as a laccolite or sill between the Arenig rocks on the east and the Llandeilo rocks on the west. The extremely sinuous outcrop tells against both these views, as does the complete absence of any sign of metamorphism in the limestones which are so frequently exposed near the felsite. The 'intrusive' view also affords no explanation either of the frequent juxtaposition of the limestone to the felsite, or of the great abundance of felsite-fragments in the tuffs and limestone-breccias.

2. That it may form one or more flows of Lower Llandeilo age—may, in fact, be the earliest event of Llandeilo time of which the district affords a record. According to this view, which, although not free from difficulties, seems to us to be the most satisfactory one available, the sinuosity of the eastern margin would simply depend on the extent to which the felsite had been removed by denudation from the Arenig rocks, and that of the western margin on the extent to which the Llandeilo tuffs had been denuded from the surface of the felsite. If almost immediately after the outpouring of the felsite the limestones were deposited, and then by explosive outbursts were disrupted, giving rise to the limestone-breccias, their frequent occurrence close to the felsite and their non-metamorphosed condition would be explicable. The abundance of felsite-fragments in the tuffs and limestone-breccias also finds a ready explanation on this hypothesis. The chief difficulty in the way of its acceptance is the great amount of variation in width of outcrop, and hence presumably in thickness, of the felsite, though the difficulty may partly be due to the repetition of the rocks by faulting or folding. Perhaps also the non-vesicular character of the red felsite and the rare occurrence of flow-structure may be taken as objections to this view.

Our conclusions with regard to the felsitic rocks may be summarized as follows :—

1. That the great red felsite (rhyolite)-mass forms a series of lava-flows of Lower Llandeilo age, which are probably penetrated here and there by minor felsite-intrusions.

2. That the remainder of the felsites are intrusions, some certainly, others probably, of post-Bala and pre-Carboniferous date, all belonging to the same general period, and that these intrusions take the form of :—
   - (i) bosses, as, for instance, the green and brown felsite-masses ;
   - (ii) dykes, as, for instance, the long intrusions which enter the south-western corner of the map, and the small patches scattered along its western border.

(*b*) The Intrusive Andesitic Rocks.

At several points in different parts of the district small intrusions of fine-grained non-porphyritic rocks of intermediate character are met with. Without microscopical examination these rocks are not easily distinguished from certain of the felsites and fine ashes, and it is not unlikely that other small masses may occur.

The following are the exposures :—

(1) A mass, exposed at various spots along a distance of about half a mile, runs in a north-north-easterly direction from a point nearly half a mile north-north-east of Tourmakeady Lodge as far as Stream C. It is a dark-green, generally compact rock,

becoming somewhat amygdaloidal in places. The rocks in its immediate neighbourhood are not well seen, but it is probably intrusive along the line of junction of the Llandeilo Beds with the (?) Bala conglomerates.

(2) A second band of very similar rock (133), often highly amygdaloidal, is traceable for a distance of about 100 yards through the coarse Arenig grits north of Mount Partry. The rock is exposed in the stream-bed and at spots near the right bank, and can be followed for some distance beyond the left bank. A closely related rock (245), showing numerous small pyroxenes in a hand-specimen, occurs about 300 yards north-west of the Monastery. A further exposure of dark andesitic rock (95) is found on the south-eastern slopes of Mount Partry, intrusive among the coarse felsitic tuffs which make up the bulk of the hill.

(3) A small intrusión of a somewhat different type of rock (292), full of small amygdules, occurs north of Gortanalderg near the western boundary of the red felsite-mass, and a large mass of a similar nature (294) at a point about 500 yards to the north-east, close by the east-and-west road.

(4) Several exposures of what are probably two intrusions (140 & 240) are seen south-east of the triangular area of Arenig rocks between Gortanalderg and Drumcoggy Rectory. The rocks are grey-green and very amygdaloidal in places; though occurring close to the Arenig Beds, they are intrusive in the felsite.

(5) A small patch of a fine-grained rock of andesitic type occurs immediately west of the augite-felsite at Shangort.

(c) The Hornblende-Lamprophyres and Dolerites.

These rocks form a series of small but interesting intrusions, principally distributed round the margin of felsite-masses.

Hornblende-lamprophyres are met with at the following points:—

(1) About 150 yards north of Gortanalderg (21). The rock here forms a more or less circular intrusion, some 50 yards in diameter, in the Llandeilo tuffs, which appear to be somewhat altered near the junction.

(2) Half a mile farther north-north-eastwards, near the left bank of Stream F, is a second small, more or less circular intrusion (43), measuring only some 10 yards across. This is also completely surrounded by Llandeilo tuffs.

(3) Two little patches, each having a visible diameter of only a few yards, are exposed near the upper part of Stream C, west of Gortanalderg. These may be continuous with one another.

(4) Intrusive in the triangular area of Arenig grits, cherts, and tuffs, nearly a mile west-south-west of Drumcoggy Rectory, is another small patch of similar rock (168).

Dolerites.—The dolerites are more numerous than the hornblende-lamprophyres, and occur at the following spots:—

(1) In the bed of Stream G, about a quarter of a mile west-north-west of Gortbunacullin, two exposures of dark-green dolerite are seen, one about 110 yards and the other about 60 yards in length. The easternmost mass (78) has felsite exposed all round it, and though felsite is only exposed on one side of the other it seems probable that the two are parts of one and the same intrusion in the felsite. The dolerite, being far more easily eroded than the felsite, has here determined the course of the stream.

(2) Two exposures (86), no doubt forming parts of one mass of very fresh amygdaloidal olivine-dolerite, occur associated with the basal Carboniferous sandstone in the lower part of Stream G, half a mile north-north-west of Srah Bridge. The dolerite appears to follow the bedding of the sandstone, and may be intruded between it and the underlying red felsite, in which case its age would be post-Carboniferous.

The uppermost 2 inches of the dolerite are not amygdaloidal, and are jointed much as is the associated sandstone. The rest of the rock, however, is very amygdaloidal. A thickness of some 2 feet is seen in a small vertical cliff on the southern side of the stream, and the rock forms the floor of the stream for some 40 yards. Both this and the dolerite-mass previously described are characterized by a rough polygonal jointing on a large scale, which is well seen in both cases in the bed of the stream.

(3) Very fresh olivine-dolerite (136) occurs in a field, a third of a mile west-north-west of Srah Bridge. Nothing is seen of the neighbouring rocks but the line of junction of the Carboniferous beds, and the red felsite probably passes quite close to this point.

(4) A similar mass of dolerite (143) is seen, not actually in place, but undoubtedly occurring at the spot, by the side of the road which leaves the main road a quarter of a mile south of Srah Bridge. Very numerous blocks built into the walls occur south-east of this point, between it and the main road, but the rock has not been met with in place.

It is not unlikely that these last three exposures may be a single mass intruded along the line of junction of the Ordovician and the Carboniferous rocks.

(5) A somewhat different type of doleritic rock (54), which resembles the diabases of North Wales, occurs at the extreme north-eastern limit of the Arenig Series exposed in the Mount Partry and Monastery region, where the mass, which is surrounded by tuff, has a visible length of about 50 yards.

IV. Petrographical Details.

(a) The Felsites.

(1) The main green-felsite intrusion.—This is formed of a pale-green rock, almost always showing in a hand-specimen large and prominent phenocrysts of quartz and sometimes of felspar. The specific gravity in a specimen (71) from near the northern end of the mass is 2·66, while others show 2·70, 2·73, and 2·75.

Sections from different parts of the mass do not exhibit much variation in structure. In each case the ground-mass contains numerous little areas which appear to be imperfect spherules. The quartz-phenocrysts show strong corrosion by the ground-mass (see Pl. V, fig. 1), and the orthoclase is much altered, sometimes showing partial replacement by epidote. A good deal of magnetite is sometimes present (79, 215). Small vesicles generally occur, occupied by calcite (71), or by chalcedony and chlorite (79, 126). A section (194), cut from a specimen taken from the extreme northern end of the long north-eastward projecting tongue, is of a rock-type similar to that of the main green-felsite mass, but contains an exceptional amount of magnetite and much apatite. Another section (214) from near the base of the tongue is of a strongly microspherulitic rock with abundant chlorite, some of which is clearly pseudomorphic after biotite.

(2) The brown-felsite intrusion.—The large felsite-mass between Shangort and Derrassa is composed of the handsomest rock in the district. In a hand-specimen it is brown or sometimes green, showing prominent quartz-crystals and numerous dark-green patches which microscopic sections show to consist of chlorite (perhaps replacing pyroxene) intergrown in some places with the felspar, which includes plagioclase as well as orthoclase. The ground-mass is felsitic, and the specific gravity of one specimen (74) is 2·70 and of another (73) 2·73.

(3) Felsite-intrusions in the Arenig and Bala rocks near Tourmakeady Lodge.—These exposures include the two long intrusions already mentioned, of which only the ends appear in the map, and several smaller intrusions. Microscopically the rock differs from that forming the main green felsite-intrusion, in the absence of any tendency to a spherulitic structure in the ground-mass. No sign of augite was to be seen in any section examined; but biotite in a more or less altered state was observed at several points. The specific gravity of one of these rocks, which contained crystals of orthoclase upwards of an inch long, is 2·68.

(4) Red felsites between Tourmakeady Lodge and Stream C.—These rocks are very variable, but the prevalent types are brown or reddish, and, in hand-specimens, often show dark

patches of chlorite. Three sections were examined: (274) is a normal felsite showing very clearly the imperfectly-spherulitic type of ground-mass, which occurs so frequently in these rocks; (273) is an unusual type, containing a considerable amount of ilmenite. At (4) the ground-mass shows a tendency to be spherulitic, little quartz occurs, and plagioclase is present as well as orthoclase. Magnetite is rather abundant, and there appears to be altered augite.

Several isolated patches of felsite lie west of the main outcrop. A small patch (284), lying south-west of the angle of Stream C, has a coarser ground-mass than is usually noticed, full of little grains of quartz. Apatite is present in some abundance.

The felsite (38) intrusive among the tuffs of Mount Partry, which may be mentioned here, contains numerous serpentinous pseudomorphs after pyroxene. Its specific gravity is 2·69.

(5) Felsites between Stream C and the east-and-west road south of Drumcoggy Rectory.—These rocks are very variable: (14) is a red felsite, while (16) and (250), from near the eastern border farther north, and (281) and (288) from near the western border, are green felsites with rather conspicuous quartz-crystals. Their microscopical appearance requires little description. The ground-mass is generally of the imperfectly-spherulitic type. In addition to the usual quartz and orthoclase-phenocrysts, altered biotite (14) is sometimes met with; and (281), a rock from the prominent felsite-crags east of Gortanalderg, contains abundant serpentinous pseudomorphs apparently after pyroxene. Apatite is fairly plentiful in this rock. Another rock (19) from this neighbourhood has a specific gravity of 2·71, and contains numerous pseudomorphs in chlorite apparently after pyroxene.

(6) Felsites between the east-and-west road south of Drumcoggy Rectory and Stream F.—While in the main these rocks are red felsites without prominent quartz-crystals, (146) & (48) are grey, with fairly prominent quartz. The imperfectly-spherulitic type of ground-mass is very well shown by (48), while in (146) bands of quartz and felspar intergrown in an imperfectly granophyric manner traverse the slide.

Along Stream F the felsite shows some modifications exceptional in the district. At (44) the rock is full of thoroughly well-rounded nodules which reach a diameter of a quarter of an inch. They are all solid, and consist entirely of white crystalline quartz.

Another rock (304) from the more easterly of the two felsite-masses on the left bank of Stream F shows strong banding on the weathered surface. In section it does not differ from the majority of the felsites of the district, except for the unusually large proportion of plagioclase present.

(7) Felsite between Stream F and Shangort.—The colour in hand-specimens shows various shades of green, grey, and

red. A rock from immediately north of Gortbunacullin Farm bridge differs from the usual type, showing a felsitic ground-mass much iron-stained and containing no quartz-phenocrysts. Another (187) near the western boundary of the felsite, due west of Srah Bridge, shows a somewhat banded appearance in the field, and in section is seen to contain a considerable amount of augite, mostly represented by pseudomorphs in chlorite.

(8) Felsites between Derrassa and Derrindaffderg.—The rocks here are principally of the red type; quartz is inconspicuous. A felsitic, instead of an imperfectly-spherulitic, type of ground-mass prevails. Flow-structure is sometimes seen (229), and the quartz-crystals are occasionally shattered as well as corroded. The specific gravities are lower than usual, those of five rocks near Stream H being respectively 2·67, 2·69, 2·70, 2·70, and 2·71.

(9) Augite-felsite intrusion of Shangort (279).—In a hand-specimen this is a dark, fresh-looking rock, with a fine-grained ground-mass in which are sparingly distributed a few small quartzes and well-cleaved felspars. In section the ground-mass is seen to be imperfectly spherulitic, quartz is rather scanty, and the felspar includes plagioclase as well as orthoclase. The augite is sometimes fresh, sometimes shows replacement partly by epidote, partly by chlorite; there are also pseudomorphs after rhombic pyroxene. The augite-crystals occasionally wrap round and enclose the ends of the smaller felspars. Magnetite is plentiful, and serpentine occurs filling small irregular vesicles. The specific gravity of (279) is 2·78. This rock might, perhaps, be classed as a quartz-andesite.

Summary of the petrological characters of the felsites.—Three principal types are recognizable, the green and brown felsite, the red felsite, and the augite-felsite. In the green and brown felsite the ground-mass is, as a rule, imperfectly spherulitic; in the red felsite it is frequently felsitic, and sometimes shows flow-structure (229). The principal phenocrysts are quartz and felspar. Quartz is always prominent in the green and brown felsites and, as a rule, shows strong corrosion by the ground-mass; occasionally, in rocks belonging to the group of red felsites (4, 19, 67) the sections examined do not show quartz-phenocrysts. The quartz-crystals are sometimes shattered (69).

Of the felspars orthoclase is always present, but it is rarely (48) fresh enough to show good twinning. Plagioclase is sometimes (304 & 279) identifiable by means of the albite twin-lamellæ, and would probably be more often recognizable if the felspars were less altered. Augite, either fresh (187) or more or less replaced by epidote (279), serpentine (38), or chlorite (19, 90), is not infrequent. Biotite in a more or less chloritized state was noted at three points.

Of accessory minerals, iron-ores are represented with remarkable frequency; ilmenite occurs occasionally (273), a general red stain due to hæmatite is very common, and at a number of points (4, 16, 68, 90) magnetite is present in some abundance. Occasionally apatite is rather plentiful (194, 281, 284). Small irregular vesicles are sometimes present filled with calcite, or with serpentine (187), or with chlorite and chalcedony, the latter mineral being sometimes spherulitic.

(*b*) The Intrusive Andesitic Rocks.[1]

Three types of these rocks are recognizable:—

1. Specimens collected from various points along the dyke west of Mount Partry are all dark compact rocks, showing little in a hand-specimen but occasional small dark amygdules. In section the main part of the rock is seen in every case to be composed of needles of plagioclase, which, from the straight or almost straight extinction, are no doubt to be referred to oligoclase. These needles, which are so disposed as to show flow-structure, have interspersed with them a relatively smaller number of larger plagioclase-phenocrysts in a more altered state. One slide (130) shows brown patches, which are probably altered augites, but ferromagnesian minerals are very scanty. Small vesicles are always present, generally occupied by a chloritic mineral. The rock exposed at (3), the point where the dyke is cut by the Bohaun road, contains vesicles the central parts of which are occupied by quartz, then follows a layer of chlorite, while the marginal parts of the vesicle are occupied by epidote and calcite (see Pl. V, fig. 4). A good deal of epidote is scattered throughout this rock. One specimen (283), taken from near the northern end of the dyke, is much more uniformly vesicular than the remainder; and the little patch of andesite (292), near the margin of the red felsite north of Gortanalderg, is of similar type, being crowded with small chlorite-filled vesicles. Very little iron-ore occurs in any of these rocks. In many respects, these rocks seem to be closely allied to those described from the St. David's district by Mr. J. V. Elsden[2] as lime-bostonites.

2. The small andesitic intrusions in the Arenig rocks from the

[1] [Subsequently to the reading of this paper, Dr. J. S. Flett kindly examined our sections of these rocks, and reported on them as follows:—'Although rocks like these have been described as andesites, andesitic dolerites, etc. in several of our memoirs and elsewhere, they are not good andesites. Their felspars are all albite-oligoclase and oligoclase, and they contain no femic minerals, only obscure pseudomorphs after pyroxene. I have compared them with the type-slides of mænites, and they are not a bit like them. I should call them spilites myself, as their characters, mainly negative I admit, are those of this group. They have the essential features of the Mid-Devonian lavas of the Plymouth area, though they are not exactly like any of the groups of spilites I am familiar with. If they contained more alkali-felspar, they would closely resemble some keratophyres. I cannot get over the belief that they are "pillow-lavas".']

[2] Quart. Journ. Geol. Soc. vol. lxi (1905) pp. 594 *et seqq.*

Mount Partry neighbourhood differ in several respects from those just described and are far more variable. One (133) has many vesicles filled with calcite and chlorite, and contains abundant magnetite very uniformly distributed in small grains. Another from Mount Partry (95) shows abundant highly-altered phenocrysts of both augite and plagioclase, together with numerous chlorite-filled vesicles, embedded in a ground-mass in which little can be recognized with certainty. Another rock (245) from north-west of the Monastery is somewhat similar, showing large highly-altered augite-phenocrysts and little that is recognizable in the ground-mass; but, in addition to the augite, there are numerous pseudomorphs in chlorite after a rhombic pyroxene, this mineral and the augite being often intergrown. No félspar-phenocrysts and no vesicles occur in this rock.

3. The rocks exposed at several points south-east of the triangular area of Arenig Beds 1 mile west-south-west of Drumcoggy Rectory are somewhat intermediate in character between dolerites and andesites. The low specific gravity, however, 2·75 of (140), shows that they are best classed with the latter rocks. They are fine-grained, rather pale rocks, and as a rule highly vesicular, the vesicles being filled with calcite and chlorite. In section the felspars are seen to be fairly fresh, but the augites are in the main replaced by epidote and chlorite. Leucoxenized ilmenite is plentiful.

(*c*) The Hornblende-Lamprophyres and Dolerites.

Hornblende-lamprophyres.—These are all dark, rather coarse-grained rocks, showing, as a rule, little in a hand-specimen except hornblende. Felspars are, however, to be seen in some varieties of the rock (21) from north of Gortanalderg. This rock has a specific gravity of 2·89. In section hornblende is in each case by far the most prominent mineral, occurring in pale-green, slightly pleochroic crystals, which are often idiomorphic (see Pl. V, fig. 2) and frequently show the normal cleavage. Very little felspar can be detected, the most prominent minerals next to the hornblende being secondary quartz and a pale-green, almost isotropic, chloritic mineral. Apatite is fairly abundant in (168), the rock from the triangular patch of Arenig Beds west-south-west of Drumcoggy Rectory, and a good deal of epidote and calcite is present.

Dolerites.—Those from the neighbourhood of Srah, and that from a quarter of a mile west-north-west of Gortbunacullin (78) (see Pl. V, fig. 3), are all dark heavy rocks of medium grain, greatly resembling some of those from the English Midlands. In section the freshest of the rocks from near Srah (86 & 136) and that from a quarter of a mile west-north-west of Gortbunacullin are seen to be very similar; they are holocrystalline, and are composed of laths of labradorite, between which are wedged grains of augite, olivine, and magnetite. The specific gravity of one of the rocks (86) from the lower part of Stream G, half a mile north-north-west of Srah Bridge, is 2·92.

The rock (143), seen along the turning which leaves the main road a quarter of a mile south of Srah Bridge, is of the same general character, but somewhat finer grained. A vesicular dolerite, from the lower part of Stream G near (86), differs from the other dolerites of that locality, in having its augite and olivine mainly replaced by serpentine.

In addition to these fresh olivine-dolcrites, an allied rock (54) occurs at a point about a quarter of a mile north of the Monastery, differing from the one just described in its weathered condition and in being devoid of olivine. In a hand-specimen the freshest examples of this rock are dark green and show numerous augites and colourless felspars. In one variety, however, the felspar-crystals are stained red. In section the rock is seen to be much decomposed. Though some fresh unaltered augite is present, most of the augite is chloritized. The felspars, which sometimes show twinning, are, as a rule, replaced by secondary quartz and calcite. Ilmenite and apatite are plentiful. The specific gravity of this rock is 2·79.

(*d*) The Tuffs and Breccias.

Four principal rock-types may be readily recognized:—

(1) The fine gritty tuffs.
(2) The fine non-gritty tuffs.
(3) The limestone-breccias.
(4) The coarse felsite-breccias or agglomerates.

(1) The fine gritty tuffs.—These rocks, which pass gradually on the one hand into pure grits, and on the other into tuffs free from gritty material, are undoubtedly the type of tuff most prevalent in the district. They are largely developed along the whole of the western outcrop of the red felsite, but are especially well seen in the neighbourhood of Gortbunacullin, where they have yielded many fossils. In hand-specimens they are usually red or brownish rocks of medium to fine grain, showing much quartz and many felsite-fragments. They often effervesce rather strongly with acid. In section the abundant angular quartz-grains are seen to be mingled with closely packed felsite-lapilli of several types, and occasional andesitic fragments, as, for example, in (167), which shows lapilli of a vesicular andesite or basalt containing fairly fresh augites. All these are united by a calcareous cement the proportion of which is variable (see Pl. V, fig. 5). Red iron-oxide is sometimes abundant, forming a stain pervading the section. Magnetite is also rather common. Occasionally a rock is met with (122) in which felspar-crystals play a prominent part.

(2) The fine non-gritty tuffs.[1]—These rocks, some of which are of Llandeilo, others of Arenig age, are principally met with in

[1] It was sometimes very difficult to distinguish between certain of the tuffs and the finer types of felsites. Mr. A. Harker, F.R.S., has kindly helped us, and we desire to tender him our sincere thanks.

the extreme northern part of the area and in the Mount Partry and St. Mary's Monastery district. They consist of closely packed lapilli of felsitic, and occasionally of andesitic rocks, with little or no gritty material. Chlorite tends to be plentiful, sometimes forming irregular patches between the lapilli, sometimes probably representing altered pyroxenes. Unaltered pyroxenes are also present among the constituents of the matrix.

Only rarely, as, for example, at (306) south-east of the brown felsitic intrusion of Shangort, were tuffs free from admixture with gritty material found in other parts of the area.

(3) The limestone-breccias.—Microscopical sections of these rocks show little variation at the various exposures, and consist of a calcareous matrix through which are scattered quartz-grains and ashy particles in varying proportions. The matrix consists principally of limestone, of a horny or not well-cleaved type; but many irregular patches of well-cleaved calcite are also invariably present. The lapilli, while predominantly of quartz-felsite, are sometimes of andesitic rocks (45).

(4) The coarse felsite-breccias or agglomerates.—The matrix of these rocks is the same as in the finer non-calcareous types of tuff.

V. The Volcanic Vent or Neck.

At a short distance south-west of Shangort occurs an oval mass of coarse breccia having a length of about 100 yards, which Sir Archibald Geikie ('Anc. Volc. Gr. Brit. vol. i, 1897, p. 253) regards as marking a vent, a view with which our own observations are in agreement. This is the only mass which we can claim with confidence as marking the position of a vent or neck.

VI. Summary and Conclusions.

We believe the general succession of the Ordovician rocks of the district to be as follows:—

3. (?) Bala Beds.

   Coarse conglomerate and sandstone, containing pebbles mainly of granite and felsite.

2. Llandeilo Beds.

   (b) Shangort Beds.—Grits and tuffs, coarse and fine—the prevalent type being a calcareous gritty tuff. In this tuff occur bedded limestones and limestone-breccias, the Tourmakeady Beds. The bedded limestones have a maximum thickness of about 30 feet, and the limestone-breccias of about 40 feet. The latter rocks are largely formed of disrupted fragments of limestone corresponding in lithological character to the bedded limestone.

   (a) Red felsite or rhyolite.—A series of flows varying much in thickness.

1. Arenig Beds.

Mount Partry Beds.

(*c*) Coarse quartzose grits with occasional chert-bands, and, towards the southern half of the area, tuffs.

(*b*) Fine grits, graptolitic slates, and cherts.

(*a*) Coarse conglomerates.

Owing to the character of the Shangort Beds, there are very few localities where the dip-angle can be obtained, and in consequence their thickness is largely conjectural. The two places where one can obtain an approximate estimate of it are respectively just south-west of Gortbunacullin and west of the Smithy bridge. At both these localities the Shangort Beds seem to be about 1000 feet thick.

The thickness of the red felsite is also a matter of extreme uncertainty. On the assumption that it is dipping at the same angle as the overlying Shangort Beds at the Smithy bridge, its thickness in this region, where it is at its narrowest, is about 300 feet. Farther north, however, there can be no doubt that the thickness is far greater than this, although probably the extra breadth of the outcrop may be partly due to a lower dip-angle, or to repetition by faulting or folding.

The Mount Partry (Arenig) Beds are well exposed in the Treanlaur stream, and on the supposition that the coarse conglomerate, in which no dips are obtainable, is dipping throughout in conformity with the grits immediately in contact with it, a total thickness of about 1300 feet of Arenig Beds is seen in this section. The coarse quartzose grit, which is comparatively thin near Mount Partry, is probably about 400 feet thick near Gortbunacullin.

Intruded into these rocks are felsites, intermediate rocks of andesitic type, hornblende-lamprophyres, and dolerites. These occur in masses, for the most part, of very small extent; but the felsite-intrusion in the northern part of the area is of very considerable dimensions.

In conclusion, we wish to tender our most hearty thanks to Mr. F. R. Cowper Reed for the large amount of trouble that he has devoted to the examination of our generally very fragmentary Llandeilo fossils. Our sincere thanks are also due to Dr. G. J. Hinde, F.R.S., for examining the radiolaria, and to the Director of the Geological Survey of Ireland for the loan of maps. Other acknowledgments are contained in the body of the paper.

VII. Palæontological Appendix.

By F. R. Cowper Reed, M.A., F.G.S.

A. General Remarks on the Fauna.

(1) The Limestone (Tourmakeady Beds).—The fauna of the limestone is not rich in species, but the fragmentary nature of the organic remains is the main obstacle to a satisfactory knowledge of its characteristics. Members of the genus *Illænus* seem to be the most abundant fossils. In spite of the matrix and mode of preservation of the fossils resembling those of the Chair of Kildare and Keisley, the facies of the fauna must be regarded as indicating a considerably lower horizon, for not only are the typical species of the Upper Bala[1] absent, but the assemblage is not that of the Middle Bala, and certain genera and representative species which occur in it are only known elsewhere from beds correlated with the Lower Bala (Llandeilo). Of such fossils we may especially note the species of *Pliomera* and *Porambonites*. The genus *Pliomera* occurs abroad only in the lower part of the Ordovician—on horizons generally regarded as homotaxial with the Arenig and Lower Bala. Such is the case in Scandinavia, the Baltic provinces of Russia, and North America, while in Scotland and Ireland it is found only in the Craighead (Stinchar) Limestone and in the Tramore Limestones respectively, which are believed to lie considerably below the Middle Bala. No undoubted representative of the genus from beds of later age than Lower Bala is definitely known. The same remarks apply to the genus *Porambonites*, which is especially characteristic of the lower stages of the Ordovician in the Baltic region. The evidence of the other fossils from the limestone is inconclusive—as either the species have a considerable vertical range, or are local in distribution, or are doubtfully identified owing to the poorness of the material available.

The new species in the fauna (to be subsequently described) do not afford any evidence contrary to the view above expressed, and the affinities of *Illænus weaveri* support it. We may therefore refer the limestone to a horizon not higher than the Lower Bala, but the facies is distinct from that met with in Wales in the Llandeilo Limestone, and no British Ordovician limestone is known with the same type of fauna. It is to the South of Ireland that one must look for features of resemblance, and in the Tramore Limestones of County Waterford, described by me in 1899 (Quart. Journ. Geol. Soc. vol. lv, pp. 718–72), we may see considerable affinities, although the Mayo beds have a much less rich and varied fauna, and lack certain characteristic forms. But the presence of the rare British genera *Pliomera* and *Porambonites*

[1] The terms 'Upper, Middle, and Lower Bala' are used here as respectively equivalent to the Ashgillian, Caradoc, and Llandeilo defined by Dr. Marr in his 'Principles of Stratigraphical Geology' (Cambridge, 1898) pp. 165 *et seqq.*

must be regarded as of especial importance, and the evidence of the faunistic relations and the probable stratigraphical equivalence of these Irish beds with parts of the Scandinavian and Russian *Orthoceras*- and Cystidean Limestones may again be emphasized.

(2) With regard to the fauna of the ashy grits (Shangort Beds) the specimens are mostly in such miserable preservation that the specific identification or even the affinities of the fossils are as a rule uncertain. However, the few which can be more satisfactorily determined indicate that there exists a certain, though not strong, difference between this fauna and that of the limestones; but this may be more apparent and accidental than real. We do not fail to note that the important genus *Pliomera* still persists, and indeed is represented by more than one species, proving that we are still dealing with Lower Bala beds. *Porambonites* also appears to occur. The possible presence of a member of the subgenus *Chasmops* suggests a somewhat higher palæontological horizon than that of the limestone, but there is nothing definite to show that the ashy grits are far removed in age from the latter. The different nature of the matrix shows the existence of different physical conditions during their accumulation, and therefore the change in the composition of the fauna may be partly due to the new environment, and the occurrence of a somewhat different assemblage of organisms may be thus accounted for. The fact that blocks of the fossiliferous limestone are found in the ashy grits is evidence that some time must have elapsed after the limestone was formed; but that they belong to the same period seems conclusively proved, palæontologically, by the presence of members of the genera *Pliomera* and *Porambonites*, and by the absence of a later or Middle Bala fauna.

The Tramore Limestones, with which the faunas of the Tourmakeady and Shangort Beds may be best compared, lie below the *Cœnograptus*-Shales, that is, below equivalents of the Glenkiln Shales, and it was suggested by me in 1899 that their lower portion corresponded with part of the *Orthoceras*-Limestone (=Arenig) of the Baltic region. It does not, however, seem necessary to regard them as of Arenig age, because, as Dr. Marr has pointed out, the migration of faunas in Ordovician times was westward, so that the older faunas of Sweden appear on slightly higher horizons in the British Isles. Moreover, the typical fauna of the British Arenig is absent. We may, therefore, look upon the Tourmakeady and Shangort Beds as probably of Lower Llandeilo rather than of Arenig age.

B. Description of New Species.

ILLÆNUS WEAVERI, sp. nov. (Pl. VI, figs. 1 *a*–1 *c*, 2, & 3.)

Description:—Head-shield slightly convex from side to side, with free cheeks arching steeply down on each side and the middle shield flattened; strongly and rather suddenly bent down in front, nearly at right angles, at about one-third of its length (that is,

immediately in front of the glabella); posterior margin not straight, but bending back on each side of the glabella. Glabella very broad and short, about one-third the length of the head-shield, with a slight independent convexity near the base; axial furrows deep, subparallel, rather sigmoidal, curving gently at first outwards, then inwards, and then outwards again, ending behind the front of the eyes. Fixed cheeks narrow, about a third of the width of the glabella, with very weak convexity at the base, and the posterior margin making an angle with the base of the glabella. Eye-lobes large, semicircular, situated far back at about one-half to two-thirds of their own length from the posterior margin of the head, and distant from the axial furrows about one-third of the width of the glabella. Facial sutures in front of the eyes subparallel and nearly straight, but curving in convergently very close to the anterior margin; facial sutures behind the eyes very short, bending outwards, slightly divergent, cutting the posterior margin at about 45°–60° immediately behind the eyes at about one-third the width of the glabella from the axial furrows. Free cheeks broad, rounded, nearly as wide as long, about two-thirds the width of the glabella, with a broad, regularly rounded genal angle, the posterior and lateral margins of the free cheeks forming one continuous semicircular curve. Eyes large, prominent, more than one-fourth of the length of the head-shield, semicircular, with a large convex lens-bearing surface steeply inclined and constricted at the base, with a surrounding wide shallow furrow. Test minutely and closely punctate, and anterior part of head-shield ornamented with a few subconcentric terrace-lines starting from about the middle of the lateral margin of the free cheeks and crossing over the middle shield.

Length of head on curve	10·0	millimetres.
Width of head on curve............	15·5	"
Width of glabella	5·0	"
Width of fixed cheek at base	1·75	"
Length of eye	2·75	"

Remarks.—This species is by far the most abundant representative of *Illænus* in the limestone exposed at (58) west of Gortbunacullin Farm. There are associated with the head-shields some imperfect pygidia, which probably belong to the same species, but their characters are not completely known (Pl. VI, fig. 2). They have a transversely semicircular shape, with the fulcrum far out, at about one-eighth the total width of the pygidium, and the truncated anterior lateral angles oblique and small, being cut off at about 45°–60° to the anterior margin, which is straight. The axis is prominent, projects on the margin, and has a decided independent convexity; it is triangular in shape, measuring about a third to a half of the length and about a third of the width of the pygidium. It is feebly defined near the apex, and when the shell is removed a median groove is seen to run from it to the posterior margin across the fascia. The caudal fascia is very wide behind, being nearly half the length of the pygidium, but at the sides it

narrows rapidly; it shows about eight or ten widely spaced, fairly regular, and continuous concentric lines. In one specimen which has lost the shell, the triangular axis shows faint traces of several annulations.

From the characters of the head-shield we may compare this species with *Illænus dalmani*, Volb.,[1] but the head-shield in ours is rather flatter posteriorly and the glabella and axial furrows much shorter. The proportions of the glabella and shape and curvature of the head more closely resemble *I. esmarkii*, Schloth.,[2] but ours does not exhibit the anterior marginal fold or the strong terrace-lines of this species. The shape of the free cheek and the large eye somewhat recall *Nileus armadillo*, Dalm. The pygidia which I believe to belong to *Illænus weaveri* are much like those of *I. dalmani*, but the truncated corners are shorter. No previously described British form is closely allied. Both the above-mentioned Scandinavian and Russian species occur in the *Orthoceras*-Limestone.

ILLÆNUS aff. CHUDLEIGHENSIS, Holm.

In addition to the above-described new species of *Illænus* from the limestone, there is another small one, from the limestone-breccia (45) in the upper part of Stream F, less completely known. But the head-shield is very broad and short, with relatively wider fixed cheeks; and in one small free cheek which may be associated with this head-shield the eye, though of somewhat similar appearance, is rather oblique and rather longer, while the genal angle is not a semicircular curve, but merely obtusely rounded, the lateral margin being straighter and slightly excavated. As far as the foregoing characters take us, this form seems allied to *Illænus chudleighensis*, Holm,[3] from the Cystidean Limestone of Russia.

PLIOMERA aff. FISCHERI (Eichw.). (Pl. VI, fig. 4.)

One imperfect pygidium of a species of *Pliomera*, from the limestone-breccia (45) of the upper part of Stream F, belongs apparently to an undescribed form; but the material is too imperfect and insufficient to apply to it a new specific designation at present. The fragmentary pygidium is broadly transverse and almost semicircular; but only three pleural lobes are preserved on one side and two on the other, while the axis only shows five segments. The anterior part of the pygidium is thus missing, though we may conjecture that its shape was much broader than that of *Pl. pseudo-articulata* (Portl.) and more closely resembled *Pl. actinura* (Dalm.) in this respect. The portion of the axis preserved is about half the length of the pygidium, and is very broadly conical, the sides being inclined at about 60° and meeting at the pointed extremity; four subequal narrow simple rings (of the first there is only a trace)

[1] Holm, 'Rev. Ostbalt. Silur. Trilob.' pt. iii, Mem. Acad. Sci. St. Petersb. ser. 7, vol. xxxiii, no. 8 (1886) p. 93 & pl. i, figs. 7–14.
[2] *Ibid.* p. 47 & pl. i, figs. 1–6.
[3] *Ibid.* p. 101 & pl. iii, figs. 1, 3, 4.

are followed by a short triangular piece wedged in between the bases of the last pair of pleuræ and forming the tip of the axis. The axial furrows are weak. The pleuræ of the lateral lobes are unfurrowed, have a flattened, elongated, and sublobate shape, and obtusely rounded ends which are free. The first and second pleuræ are in contact for nearly three-fourths of their length, and widen a little towards their extremities, diverging from the axial line. The second and third pleuræ are likewise in contact, but only for a little more than half their length. The third pair of pleuræ are nearly parallel-sided, and run back in contact in the middle line for nearly half their length with only a very slight divergence. The three pairs of pleuræ arise from the last three rings of the axis, and the last pair therefore does not correspond with the triangular segment at the tip of the axis, which thus seems to be devoid of pleuræ or to be of the nature of a post-axial piece.

The general characters of this pygidium suggest a comparison with *Pl. actinura* (Dalm.) rather than with *Pl. pseudo-articulata*; but it has the divergent pleuræ and broadly conical axis of the first with the obtusely-ended pleuræ of the second. The absence of the fusion of the members of the last pair of pleuræ which is so marked in *Pl. pseudo-articulata* is a striking difference, and the blunt extremities of the pleuræ are in contrast with the pointed extremities of those in *Pl. actinura*.[1]

In *Pl. fischeri* (Eichw.)[2] we find the axis of the pygidium of not quite so sharply conical a shape, but the terminal triangular segment bears no pleuræ. The blunt extremities of the pleuræ also agree with this Mayo specimen, and the manner in which the last pair of pleuræ lie in median contact behind the axis. All the pleuræ, however, lie subparallel, diverging less in a fan-shaped way; they are also, relatively, not so broad. But it is undoubtedly the case that *Pl. fischeri* and this Irish species are closely allied.

Dimensions:—

Length of fragmentary pygidium.........	9	millimetres.
Width of fragmentary pygidium	17	,,
Length of axis................................	4·5	,,
Length of 3rd pleuræ	5·5	,,

PLIOMERA aff. BARRANDEI, Billings. (Pl. VI, fig. 5.)

There is one imperfect pygidium in the rotten crumbling rock from the spot (293), 1 mile west of Drumcoggy Rectory, which bears a great resemblance to Billings's *Amphion* [=*Pliomera*] *barrandei* from the Quebec Group.[3] The axis is perfect, as also the left lateral lobe and pleural spines, though their preservation as external impressions renders the characters somewhat difficult

[1] C. Wiman, 'Studien über das Nordbaltische Silurgebiet, II' Bull. Geol. Inst. Univ. Upsala, vol. viii (1907) p. 87 & pl. vii, figs. 9–12.

[2] F. Schmidt, 'Rev. Ostbalt. Silur. Trilob.' pt. i, Mem. Acad. Sci. St. Petersb. ser. 7, vol. xxx, no. 1 (1881) p. 191 & pl. xiii, figs. 1–8.

[3] E. Billings, 'Palæoz. Foss. Canada' vol. i (1865) p. 288 & fig. 277 *b*.

to make out. The axis has the same shape, five or six rings, and triangular terminal segment, as Billings figures and describes, and the five rounded pleuræ with free pointed recurved ends appear to be closely similar. The length of our specimen with the spines is about 12 millimetres, and its width about 20 to 24 mm.

CYBELE CONNEMARICA, sp. nov. (Pl. VI, figs. 6 & 7.)

Description:—Pygidium subpentagonal, as wide as long, greatest width at the level of the posterior end of the axis, gently convex; lateral lobes bent down slightly in front but steeply behind. Axis conical, tapering rather rapidly at about 30°, obtusely pointed, annulated for its whole length, more than a third of the width of the pygidium at the anterior end and extending fully three-fourths of its length; composed of twelve or thirteen complete rings, separated by strong equal furrows, deepest at the sides; traces of lateral nodules to rings. Axial furrows well marked. Narrow, elongated, ridged postaxial piece extending from the tip of the axis to the posterior margin of the pygidium, not sharply defined from the lateral lobes. Lateral lobes composed of nine or ten pairs of pleuræ, of which the first three are subequal in size and the remainder successively decrease in size and strength, the ninth being very slender and short and lying close up against the last three or four rings of the axis and not extending behind its tip; faint traces of a still smaller linear tenth rib are occasionally visible. The first pleuræ bend back strongly at about a third of their length, and arch backwards almost parallel to the axis, reaching back as far as its tip; the following pleuræ are less strongly curved, and become successively straighter and subparallel to the axis, curving inwards somewhat posteriorly. The first five pairs of pleuræ end in free obtuse short points on the margin, and are separated by strong interpleural furrows; the fifth pleuræ curve inwards to meet in the middle line behind the post-axial piece; the other four or five pleuræ are enclosed, do not reach the margin, and end weakly against the sides of the post-axial piece. A narrow anterior band is occasionally visible on the anterior edge of the first three pleuræ, but usually they appear to be simple and unfurrowed. Surface of pygidium granulated, with a few irregularly disposed tubercles on the pleuræ.

Dimensions (average):—

Length of pygidium	8	millimetres.
Width of pygidium	8	„
Length of axis	6·5	„
Width of axis at anterior end	2·5	„

Remarks.—This species, of which only the pygidium is known, appears to be allied to *Cybele bellatula* (Dalm.),[1] but the complete condition of the axial rings and their much smaller number, as well as the different characters of the pleuræ of the lateral lobes, mark

[1] For references, see F. R. C. Reed, 'Lower Palæozoic Trilobites of Girvan' pt. iii, Monogr. Palæont. Soc. vol. lx (1906) p. 124.

it off. The name *Cybele connemarica* is accordingly suggested for this new species, which comes from the calcareous ashy grit of Gortbunacullin (42), Shangort (322), and the Smithy bridge (5), and is not uncommon at these places.

ENCRINURUS sp.

Description.—Pygidium broadly subpentagonal, somewhat arched down behind; lateral lobes bent down steeply on each side. Axis broadly conical, pointed, not reaching the posterior end of the pygidium, tapering rather rapidly, annulated for its whole length, composed of thirteen complete rings, of which the first six are strong and broad, but the posterior rings narrow and weak; strong articulating ring at the anterior end. Lateral lobes composed of eight rounded simple ribs corresponding to the first eight axial rings, sloping back obliquely, bent down and back at a weak fulcrum situated at half their length. The ribs successively decrease in strength and length, the anterior five or six pairs being strong and reaching the margin with short free obtuse ends, but the posterior two or three pairs being narrow and weak and curving somewhat inwards so as to meet behind the tip of the axis, the 8th pair being very small and slender and closely pressed against the side of the axis. Interpleural furrows narrow, well-marked. Surface of axis coarsely granulated, with a single line of granules arranged along the middle of the first five or six pleuræ on the lateral lobes.

Remarks.—There is only one poor specimen of this type of pygidium in the collection, and it was found in the gritty ash (322) a third of a mile south-south-west of Shangort. It differs from the well-known *E. sexcostatus*, Salter,[1] by its more numerous lateral ribs and by fewer but complete axial rings. The Irish species *E. fallax*, Reed,[2] likewise has fewer lateral ribs and a different ornamentation. *E. multisegmentatus* (Portl.)[3] and *E. multiplicatus*, Salter,[4] have, on the other hand, many more lateral ribs and axial rings, many of which are incomplete. For the shape of the pygidium, the course of the lateral ribs, and the tapering and annulation of the axis, *E. varicostatus*, Walcott,[5] and *E. vannulus*, Clarke,[6] from the Trenton Limestone, may be compared; but apparently this Irish species is new. In the absence of all knowledge of the characters of the head-shield, Dr. Vogdes's[7] classification of the European and American species of the genus is not of much assistance.

[1] J. W. Salter, Mem. Geol. Surv. U. K. dec. vii (1853) no. 4, pl. iv, figs. 1–12.
[2] F. R. C. Reed, Quart. Journ. Geol. Soc. vol. lv (1899) p. 753 & pl. xlix, figs. 9–12.
[3] *Id.* 'Lower Palæoz. Trilobites of Girvan' pt. iii (1906) p. 122 & pl. xvi, figs. 9–11 *a*; see also Geol. Mag. dec. v, vol. i (1904) p. 387 & pl. xii, fig. 5.
[4] *Id.* Geol. Mag. dec. iv, vol. viii (1901) p. 107 & pl. vii, fig. 3.
[5] Safford & Vogdes, Proc. Acad. Nat. Sci. Philad. 1889, p. 167 & fig. 2.
[6] J. M. Clarke, 'Geol. Minnesota: Palæont.' vol. iii, pt. ii (1897) p. 740 & fig. 57.
[7] A. W. Vogdes, Trans. San Diego Soc. Nat. Hist. vol. i, no. 2 (1907) pp. 61–82 & pls. i–iii.

ACIDASPIS (?) sp. (Pl. VI, fig. 8.)

One imperfect pygidium, the generic reference of which is somewhat uncertain, has been found in the calcareous ashy grit (212), south of Gortbunacullin. Only the spinose margin and a small piece of the edge of the lateral lobes are preserved.

In shape the pygidium is broadly parabolic or semielliptical, about twice as wide as long; the surface was apparently rather strongly convex, and the lateral lobes, which are devoid at the edge of all traces of pleuræ, descend steeply to the narrow flattened border, which is furnished with five pairs of somewhat flattened spines, horizontally extended and subparallel, being all directed nearly straight back with scarcely any perceptible divergence. They are of subequal size and stoutness, and situated at equal distances apart; their length cannot be ascertained, as their ends are broken off, but the portions remaining are about half the length of the pygidium. They taper very slowly, and all apparently at the same rate, and it is probable that they were all of subequal length. The surface of the lateral lobes and of the spines is covered with minute tubercles.

Dimensions.—Length (without spines) = 2·75 millimetres; width = 6 mm.

Remarks.—It is possible that this fragmentary pygidium should be placed in the genus *Acidaspis*, but the marginal portion of a pygidium like *Apatocephalus serratus* (Bœck), with the spines more regularly spaced, would have a very similar appearance to our fossil.

APATOCEPHALUS (?) sp. (Pl. VI, fig. 9.)

One isolated free cheek measuring about 10 millimetres in length and 5 mm. in width, occurring among the specimens from (322), the gritty ash a third of a mile south-south-west of Shangort, shows features which demand a special notice of it.

The cheek is elongated and narrow, about twice as long as wide, and the genal angle is furnished with a spine. The surface of the cheek is convex, and rises rather steeply from the marginal furrow; it is covered with rather coarse, low, closely set tubercles and bears a large, gently curved eye, which is about half the length of the cheek, is placed far back but does not touch the neck-furrow behind, and is supported by a steep, low, smooth base surrounded by a wide shallow furrow: the lenses and surface of the eye itself are unfortunately not preserved. The lateral margin of the cheek has but a slightly arched outline, and is provided with a moderately-wide smooth border, inclined less steeply than the surface of the cheek, from which it is marked off by a shallow furrow, and provided with a rounded rim. A conspicuous but low rounded swelling forms an oval boss at the angle of junction of the marginal and neck-furrows, and is partly separated from the convex surface of the cheek. The neck-segment is smooth and marked off by a strong neck-furrow, which is directed nearly at right angles to the marginal furrow. The genal angle is provided with a long gently-tapering spine which is in

continuation of the lateral border, but is angularly ridged along its length; the tip is broken, but the spine is at least three-fourths of the length of the whole cheek. The facial suture has its anterior branch poorly shown, but it seems to arch strongly inwards and slightly backwards to the eye, which it meets at nearly a right angle; the posterior branch bends out behind the eye, curving back rather steeply to cut the posterior margin of the head-shield at about 60° and about half way between the base of the eye and the lateral edge of the cheek.

The generic reference of this solitary free cheek is somewhat doubtful, but it much resembles in convexity and shape, position and size of eye, and genal spine, the trilobite from the Trenton Limestone described as *Bathyurus extans* (Hall),[1] and chosen by Billings as the type of that genus. It cannot be referred to *Asaphus* or to any of its subgenera, but in many respects it recalls some species of *Proetus*. Most of all it resembles the free cheek of some species of *Apatocephalus*, if we accept Prof. Brögger's[2] reference of Salter's species *Conocoryphe invita* to this genus. A species of *Apatocephalus* has been described by me[3] from the Tramore Limestone of County Waterford.

TELEPHUS HIBERNICUS, sp. nov. (Pl. VI, figs. 10 & 11.)

Several small detached head-shields of a trilobite, with the peculiar characters of *Telephus*, occur in the crystalline reddish limestone (58) exposed west of Gortbunacullin Farm bridge. None are very well preserved; but, by piecing together the evidence from the different specimens, the following description can be given.

Head-shield transverse, more than twice as wide as long. Glabella broadly semioval to subquadrate, nearly as wide as long, narrowing a little anteriorly, strongly convex, rounded in front. Occipital furrow slightly arched forward in the middle or straight; occipital segment simple. Axial furrows sharp, moderately strong, slightly convergent anteriorly. Cheeks much lower and less convex than the glabella, almost horizontally extended or slightly arched down on each side, of rounded or subtriangular shape, nearly as broad as long, surrounded by a flattened border, which broadens gradually to the middle, then decreases in width until it merges into the narrow anterior border in front of the glabella. Marginal furrow sharp, but not deeply impressed. Glabella and cheeks minutely tuberculated.

Dimensions.—Length = about 3·0 millimetres; width = about 6·5 mm.

Remarks.—This species seems almost indistinguishable from

[1] J. Hall, 'Palæont. N.Y.' vol. i (1847) p. 228 & pl. lx, figs. 2–2 *a*; E. Billings, 'Geol. Canada' (Geol. Surv. Canada) 1863, p. 153 & fig. 114.

[2] W. C. Brögger, 'Verbreit. der *Euloma-Niobe* Fauna in Europa' Nyt Mag. f. Naturvidensk. vol. xxxvi (1898) pp. 175, 184, & 202.

[3] F. R. C. Reed, Quart. Journ. Geol. Soc. vol. lv (1899) p. 758 & pl. xlix, figs. 14–16 (*Tramoria punctata*); see also Geol. Mag. dec. iv, vol. vii (1900) p. 46.

T. bicuspis, Angelin,[1] but no pair of anterior spines has been observed in any of our specimens. The shape of the glabella, relatively wider cheeks, and absence of a median occipital spine distinguish it from *T. fractus*, Barr., which I have described [2] from the Whitehouse Group in the Girvan district.

SYMPHYSURUS (?) sp. (Pl. VI, fig. 12.)

One interior of an imperfect head-shield from the Shangort Beds, found south-south-west of Shangort, may doubtfully be referred to *Symphysurus* or *Nileus*. The almost perpendicular course of the posterior branch of the facial suture from the eye to the posterior margin of the head-shield, the large prominent semicircular eye-lobe, the narrowness of the fixed cheek, the shape of the glabella, as evidenced by the course of the axial furrows running straight forwards from the posterior margin to beyond the eye with a slight concave outward curvature, and the marked independent convexity of the wide subcylindrical glabella are features which recall *Symphysurus angustatus* (Bœck).[3] Unfortunately, the front part and left-hand side of the head-shield are missing; and their absence, coupled with the poor state of preservation of the rest of the specimen, makes a satisfactory identification of the genus uncertain.

ACROTRETA (?) HIBERNICA, sp. nov. (Pl. VI, figs. 13 *a*, 13 *b*, & 13 *c*.)

There is one pedicle-valve and its external impression from the limestone of the upper part of Stream F (45), which may probably be assigned to the genus *Acrotreta*, although its ornamentation resembles that of *Acrothele granulata*, Linnarsson.

The pedicle-valve is regularly oval, about one and a half times as long as broad, gently convex and very obliquely conical; the beak is elevated, and the subapical pseudo-area is short and steep, with a broad median shallow groove. The apex of the valve being broken off, it is uncertain whether a foramen was present. The ornamentation of the surface is very well preserved, and is a conspicuous feature; it consists of fine, concentric, somewhat irregular lines, elevated at close intervals into small elongated papillæ, which are very minute near the apex but increase regularly in size in the successive concentric rows to the margin. An obscure alternate arrangement of the papillæ is here and there observable, but for the most part they are irregularly placed, though closely set.

Dimensions.—Length = 8 millimetres; width = 5 mm.; height = about 2 mm.

Species of both *Acrothele* (*A. granulata*, Linnarsson) and of *Acrotreta* have been recorded by Davidson [4] from the British and

1 N. P. Angelin, 'Palæont. Scand.' 1854, p. 91 & pl. xli, fig. 22.

2 F. R. C. Reed, 'Lower Palæozoic Trilobites of Girvan' pt. i, Monogr. Palæont. Soc. vol. lvii (1903) p. 44 & pl. iv, fig. 11.

3 W. C. Brögger, 'Die Silur. Etagen 2 & 3 im Kristianiagebiet, &c.' (Christiania, 1882), p. 60 & pl. iii, figs. 9–9 *a*.

4 T. Davidson, 'Monogr. Brit. Foss. Brach.' vol. iii, p. 343 & pl. xlix, figs. 36–40, Palæont. Soc. vol. xxiv (1870); Suppl. vol. v, p. 213 & pl. xvi, figs. 21–23 (*Acrotreta nicholsoni*); Suppl. vol. v, p. 214 & pl. xvi, figs. 29–30 (*Acrothele granulata*), Palæont. Soc. vol. xxxvii (1883).

the Irish Llandeilo. The presence of the grooved area inclines me to place this shell in the genus *Acrotreta*, as now understood.[1]

CAMERELLA THOMSONI (Davidson).

The fossil which has been referred to this species [2] occurs rather frequently in both the Tourmakeady and the Shangort Beds, but it is usually in a poor state of preservation. Its external resemblance to *Rhynchonella digitata* (Leucht.) [3] of the *Expansus*-Shales of Scandinavia is deserving of notice, but we are without knowledge of the internal characters of either species. *C. thomsoni* occurs typically in the Craighead Limestone of Girvan.

STREPTIS AFFINIS, sp. nov. (Pl. VI, figs. 14 *a* & 14 *b*.)

Description.—Shell transversely oval, nearly twice as wide as long, symmetrically bilobate. Pedicle-valve moderately convex, composed of two equal rounded lobes, divided by a shallow median longitudinal sulcus which causes the central emargination of the anterior border; beak somewhat swollen, small, incurved, rising a little above the straight hinge-line; hinge-area not preserved; hinge-line rather less than the width of the shell. Surface of valve marked by about twenty-five regular, equidistant, and subequal, closely-placed, low, rounded, concentric ridges following the outline of the shell, and separated one from the other by sharply impressed lines; ornamentation of ridges consisting of small, round, subequal, pointed tubercles, rather widely separated and more or less regularly disposed in lines radiating from the beak, with some minute granules occasionally interspersed.

Interior of pedicle-valve with a narrow, transverse, umbonal ridge or lamella cutting off a small umbonal cavity and connecting the small pair of teeth; a thin median septum also partly divides the umbonal cavity longitudinally. In front of the transverse ridge lies a pair of bilobed, sub-pyriform, slightly divergent muscle-scars (diductors) extending nearly half the length of the valve, rather more deeply impressed in front than behind, and separated for their whole length by a partly-fused pair of narrow, linear adductor-impressions, which anteriorly diverge slightly and expand into small, short, suboval scars lying in front of the diductors. Three pairs of short vascular sinuses, deeply excavated at their origin, diverge from the sides and front of the diductor-scars.

Dimensions.—Length of pedicle-valve = about 6·5 millimetres; width of the same = about 11 mm.

Remarks.—There is available for examination one nearly perfect pedicle-valve of this brachiopod, represented by the external impression of the shell and the internal cast of the same individual, together with several fragments of valves. All come from the same

[1] C. D. Walcott, Proc. U.S. Nat. Mus. vol. xxv (1903) pp. 577–601; and Smithsonian Miscell. Coll. vol. liii (1908) no. 1811, p. 146.

[2] T. Davidson, 'Monogr. Brit. Foss. Brach.' vol. iii, p. 186 & pl. xxiv, fig. 18, Palæont. Soc. vol. xxii (1868).

[3] W. C. Brögger, 'Die Silur. Etagen 2 & 3' p. 52 & pl. xi, figs. 2 *a*–2 *c*.

locality and horizon, the gritty ash (322) a third of a mile south-south-west of Shangort. The affinity of this species with *Streptis monilifera* (M'Coy),[1] which occurs in the Upper Bala Limestone of the Chair of Kildare, is obvious; but it differs in the greater number of concentric ridges (25 instead of eight or nine), in the tubercles upon them being widely separated instead of closely placed or contiguous, and in the interspaces between the ridges being narrow impressed lines instead of wide concave grooves. The internal characters of *Streptis* have not been previously described, and we may note in them some resemblance to those of *Mimulus aunglokensis*, Reed,[2] from the Silurian of Burma, especially in the presence of the umbonal chamber; but there is in this Irish species of *Streptis* no median septum between the diductors. The only other known species of *Streptis* in the British Isles is *Str. grayi*, Dav., from the Wenlock Series, but this is asymmetric, and the concentric ridges are fimbriated.

EXPLANATION OF PLATES IV–VI.

Plate IV.

Geological map of the Tourmakeady District (County Mayo), on the scale of 6 inches to the mile.

Plate V.

[All the figures are magnified 28 diameters.]

Fig. 1. Quartz-felsite (73). Derrassa. The main part of this figure is occupied by a large strongly-corroded quartz-crystal. Parts of two much-weathered felspars are seen. The little pale spots in the ground-mass are principally quartz. (See p. 133.)

2. Hornblende-lamprophyre (21). Gortanalderg. The figure shows one well-terminated cross-section of a hornblende-crystal, exhibiting the two cleavages. Parts of another large and several smaller hornblendes are seen. The rest of the figure consists principally of quartz. (See p. 137.)

3. Olivine-dolerite (78). West of Gortbunacullin. The most prominent objects are the labradorite-crystals. Between these are small grains of augite, olivine, and magnetite, not clearly differentiated in the figure. (See p. 137.)

4. Spilite (3). Half a mile north of the Lodge, Tourmakeady. The most prominent object in this figure is an amygdule, the main part of which is formed by quartz, while external to this comes a double layer of chlorite, and finally a discontinuous layer consisting partly of calcite, partly of epidote. Surrounding the amygdule are numerous little felspar-crystals, which extinguish practically straight and are probably oligoclase. (See p. 136.)

5. Calcareous tuff (320). West of Shangort. A quartz-grain and parts of several felsite-lapilli are seen embedded in a calcareous matrix. (See p. 138.)

6. Radiolarian chert (330). West of Gortanalderg. Sections of seven radiolaria are seen wholly or in part. (See p. 111.)

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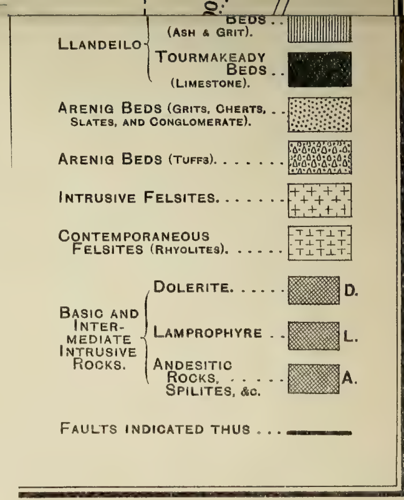
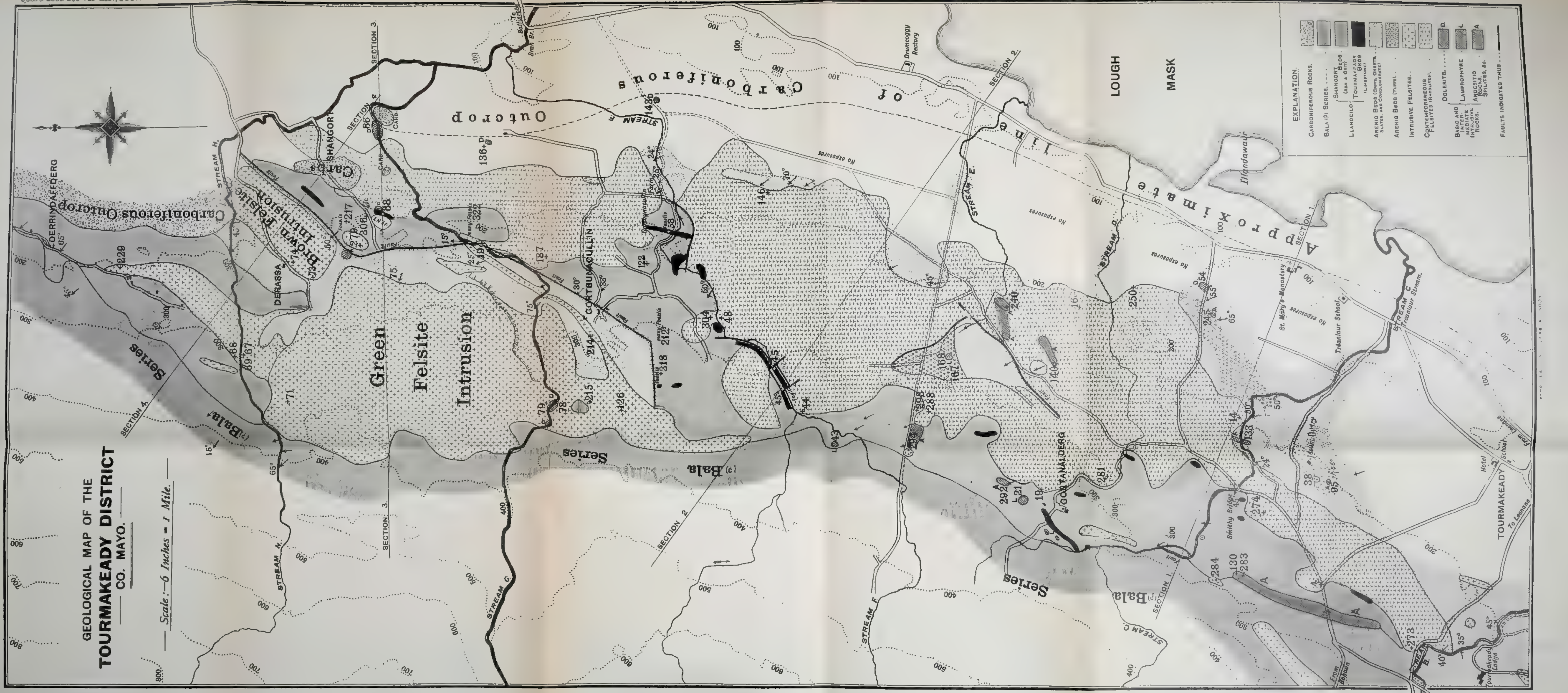
[1] F. M'Coy, 'Silur. Foss. Ireland' 1846, p. 25 & pl. iii, fig. 3; T. Davidson, 'Monogr. Brit. Foss. Brach.' vol. iii, p. 200 & pl. xxv, figs. 3–5, Palæont. Soc. vol. xxii (1868).

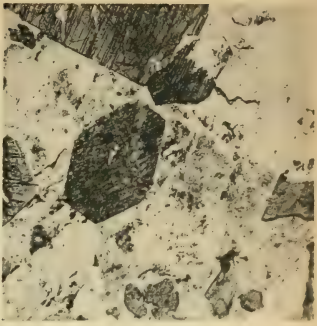
[2] F. R. C. Reed, 'Palæont. Indica' n. s. vol. ii, Mem. 3 (1906) p. 100 & pl. vi, figs. 13–17 *a*.


Beds . .
(Ash & Grit).
Llandeilo
Tourmakeady Beds . .
(Limestone).
Arenig Beds (Grits, Cherts, Slates, and Conglomerate). . .
Arenig Beds (Tuffs). . . . . . .
Intrusive Felsites. . . . . . .
Contemporaneous Felsites (Rhyolites). . . . . .
Basic and Inter-mediate Intrusive Rocks.
Dolerite. . . . . . D.
Lamprophyre . . L.
Andesitic Rocks, ... Spilites, &c. A.
Faults indicated thus . . .


GEOLOGICAL MAP OF THE
TOURMAKEADY DISTRICT
CO. MAYO.
Scale :—6 Inches = 1 Mile.
EXPLANATION.
Carboniferous Rocks
Bala (?) Series
Shangort Beds (Ash & Grit)
Llandeilo
Tourmakeady Beds (Limestone)
Arenig Beds (Grits, Cherts, Slates, and Conglomerates)
Arenig Beds (Tuffs)
Intrusive Felsites
Contemporaneous Felsites (Rhyolites)
Basic and Intermediate Intrusive Rocks
Dolerite D.
Lamprophyre L
Andesitic Rocks (Spilites &c.) A
Faults indicated thus
LOUGH MASK
Approximate line of Carboniferous Outcrop
Carboniferous Outcrop
Green Felsite Intrusion
Brown Felsite Intrusion
(?) Bala Series
Derrindafferg
Derassa
Shangort
Gortbunacullin
Gortanalderg
Drumcoggy Rectory
St. Mary's Monastery
Treanlaur School
Smithy Bridge
Hotel
School
TOURMAKEADY
Stream C, Treanlaur Stream
Stream D
Stream E
Stream F
Stream G
Stream H
Section 1
Section 2
Section 3
Section 4
No exposures
Ilandawaun
To Leenane
Tourmakeady Lodge

1

2



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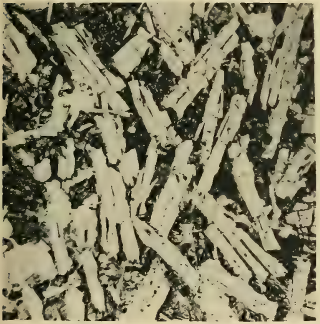

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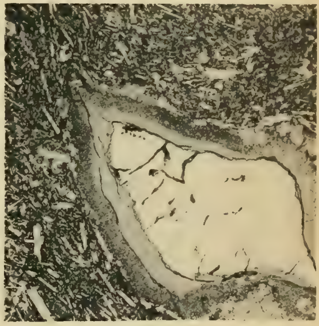

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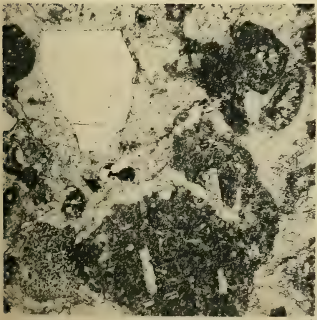

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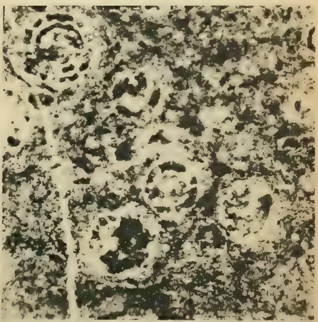
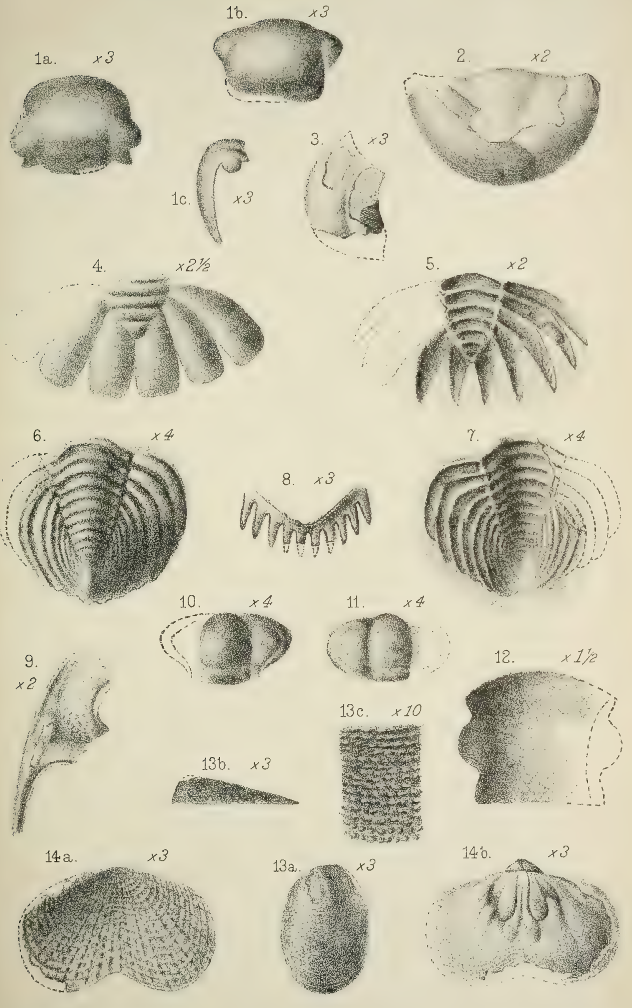


S. H. Reynolds, Photo-micro. *Bemrose, Collo, Derby*

ROCKS FROM TOURMAKEADY.



A.H. Searle del. et lith. West, Newman imp.

PALAEOZOIC FOSSILS FROM TOURMAKEADY.

Plate VI.

Fig. 1 *a*. *Illænus weaveri*, sp. nov. Head-shield, seen from above. ×3.
1 *b*. Do. Head-shield, seen from the front. ×3.
1 *c*. Do. Head-shield, seen from the side. ×3.
2. Do. Pygidium. ×2.
3. Do. Free cheek. × 3.
4. *Pliomera* aff. *fischeri*, Eichwald. Pygidium. ×$2\frac{1}{2}$.
5. *Pliomera* aff. *barrandei* (Billings). Pygidium. ×2.
6. *Cybele connemarica*, sp. nov. Pygidium. ×4.
7. Do. Pygidium: impression. ×4.
8. *Acidaspis (?)* sp. Pygidium. ×3.
9. *Apatocephalus (?)* sp. Free cheek. × 2.
10. *Telephus hibernicus*, sp. nov. Head-shield. ×4.
11. Do. Head-shield. ×4.
12. *Symphysurus (?)* sp. Imperfect head-shield. ×$1\frac{1}{2}$.
13 *a*. *Acrotreta (?) hibernica*, sp. nov. Pedicle-valve. ×3.
13 *b*. Do. Pedicle-valve: side view. ×3.
13 *c*. Do. Pedicle-valve: ornamentation. ×10.
14 *a*. *Streptis affinis*, sp. nov. Impression of exterior of pedicle-valve. ×3.
14 *b*. Do. Cast of interior of same valve. ×3.

Discussion.

Prof. Watts congratulated the Authors in having made a definite correlation between the rocks of this area and of British areas, such as Girvan, in which the succession was well known. He was also pleased to find that it might now be regarded as settled, that the contemporaneous igneous rocks of this area were not of Silurian age.

Mr. H. H. Thomas, in view of the great thickness of strata between the *Tetragraptus*-Beds and the Llandeilo Flags in Wales, suggested the possibility of the lowest rhyolite being of earlier date than the Llandeilo, especially as there was evidence of volcanic activity in Wales at a low horizon in the *Didymograptus-bifidus* Beds.

Mr. B. Smith, commenting upon the resemblance between the Tourmakeady Beds and those of the same age in the Girvan district, mentioned by Prof. Watts, pointed out that the rocks of the Pomeroy Inlier in County Tyrone (the Desertcreat Group, of Upper Ordovician age), which lay almost upon the same line of strike, had their nearest equivalents in the Drummuck Beds of Girvan. A link between the Ordovician fauna of Ireland and of parts of Europe was also furnished by the highest Ashgillian Beds (Tirnaskea), in which a trilobitic fauna was associated with a graptolitic one. For example, the recurrent trilobite of Barrande's 'colonies,' *Æglina rediviva*, recognized here for the first time in Ireland, was found together with *Dicellograptus anceps*, the highest zone-fossil of the Southern Uplands.

Mr. O. T. Jones remarked that a number of complicated events appeared to have been crowded into a comparatively limited space of time, if the earliest volcanic activity were referred to the Llandeilo Period. This phase was presumably followed by the deposition and consolidation of the limestone, which was disrupted together with the felsite to form the felsite-breccia; yet the fossils of the higher beds still indicated an horizon of Llandeilo-Flag age. It seemed to the speaker that the conglomerate-beds bounding the area on

the west had nothing in common with the underlying rocks, inasmuch as they had a very different strike, rested upon different horizons in different places, and appeared to be unaffected by the faults which traversed the underlying rocks.

Mr. J. V. Elsden remarked upon the suggested resemblance between certain of the intrusive andesitic rocks, mentioned in the paper, and rocks from North Pembrokeshire, which he had described as lime-bostonites, on account of their chemical and mineralogical identity with Prof. Brögger's mænite. The Pembrokeshire rock contained irregular chloritic areas and a little quartz, possibly of secondary origin, with occasional large felspars, in addition to the oligoclase-laths of which the mass of the rock was composed. He could not say how far this description agreed with that of the amygdaloidal andesitic rock described by Prof. Reynolds. He recalled the fact that Mr. Cowper Reed had found a very similar rock in the Waterford area.

The President (Prof. Sollas) desired to join in congratulating the Authors on their success, in determining the age and succession of the rocks in this difficult and interesting area: the transference of the series from the Silurian to the Ordovician was of great importance in its bearing on general views. Some of the igneous rocks had a remarkably fresh appearance, suggestive of Tertiary age.

Mr. C. I. Gardiner expressed the thanks of the Authors for the very kind manner in which their paper had been received. In reply to the criticism that there was a very small thickness of Arenig Beds between the *Didymograptus-bifidus* horizon and the Llandeilo, he pointed out that the latter rocks do not always rest on the same Arenig horizon, and consequently there might very well exist in the district Arenig Beds higher than any now exposed. With regard to the doubt thrown on the possibility of a limestone being deposited, disrupted, and its fragments embedded in a tuff, all in Llandeilo times, he pointed out that the fossil evidence conclusively proved that the limestone and the tuffs were both of Llandeilo age.

In reply to the suggestion that the coarse conglomerates and grit on the west should be classed as of Llandovery age, he observed that these rocks were merely taken as marking the western limit of the area, and that, as they had previously been taken to be the same bed as the coarse Arenig conglomerate on the east, the Authors had perforce mentioned the reasons which had led them to reject this view. The study of these western deposits was, however, outside the objects of the paper; and so, as their age seemed a matter of doubt, the rocks were always referred to as of (?) Bala age.

Prof. Reynolds, in reply to Mr. Elsden, said that the rocks which the Authors had compared with those described as lime-bostonites from the St. David's district, were fine-grained, commonly amygdaloidal rocks, often showing flow-structure. The prevalent mineral was a felspar, apparently oligoclase; no quartz was present; and but rarely any ferromagnesian constituent.

7. NOTE *on some* GEOLOGICAL FEATURES *observable at the* CARPALLA CHINA-CLAY PIT *in the* PARISH *of* ST. STEPHEN'S (CORNWALL). By JOSEPH HENRY COLLINS, F.G.S. (Read February 10th, 1909.)

[PLATE VII.]

THIS clay-work is situated on the Burngullow branch of the Great Western Railway, about a mile and a half north-west of Burngullow Station, at an elevation of about 550 feet above sea-level.

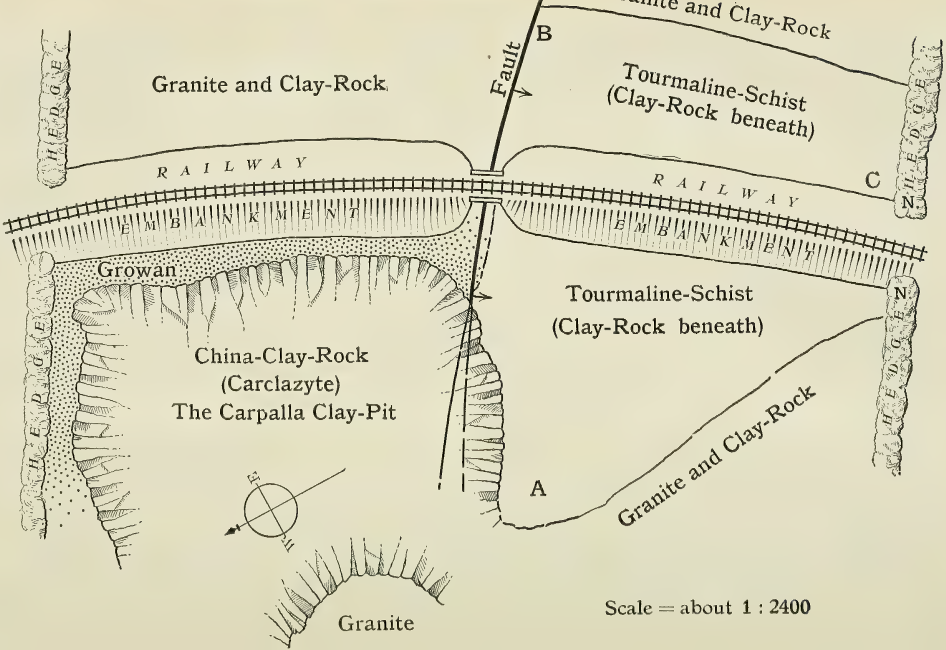
The land slopes generally from the east towards a rather deep valley, the railway running from nearly south to north along the eastern edge of the valley, on a low embankment across two fields where the inclination is very gentle. About the middle of its length, the embankment is traversed from east to west by an accommodation-road, over which the line is carried by an arch of masonry. East of the railway and also on the southern portion of the west side, the ground has been very thoroughly explored by means of pits and shafts, while the northern portion of the west side is fully exposed by the great clay-excavation (the Carpalla clay-pit), now over 100 feet deep.

The surface-soil or 'meat-earth,' generally almost black and of a peaty character, covers or has covered the whole estate to a depth of 6 inches or more. Beneath this is everywhere a 'growan' [1] or stratum of subsoil, varying in depth from 2 up to 10 or 12 feet. On each side of the railway from the hedge marked NN on the accompanying plan (fig. 1, p. 156), as far as the accommodation-road above mentioned, this growan rests upon a stratified rock locally known as killas, which is here really a well-marked tourmaline-schist; beyond the road, it rests upon an altered granite known as china-clay rock or carclazyte, and colloquially termed 'clay,' from which the true china-clay or kaolin is obtained by washing. At the northern end of the embankment, the clay-rock passes under a rather soft variety of granite, the felspar of which has not been sufficiently kaolinized to be of value to the clay-worker. This soft granite is also capped by a layer of growan.

The accommodation-road already mentioned passes along a line of fault which has let down the ground to the south for some fathoms. There is no indication of this fault at the surface other than a series of springs; but very slight excavation suffices to show the difference of the rocks on either side of the springs. The course of this fault is roughly east and west, and its hade or underlie about 30 degrees from the vertical towards the south. Nothing is known of its extension into the hill eastwards; in the opposite direction it soon splits up, and is lost in the decomposed granite of the valley;

[1] Growan is the local term for a disintegrated subsoil which is mainly of granitic origin.

FIG. 1.- SKETCH-PLAN OF THE CARPALLA CLAY-PIT AND ITS IMMEDIATE SURROUNDINGS.



it is also soon lost as it passes down into the china-clay rock of the great pit.

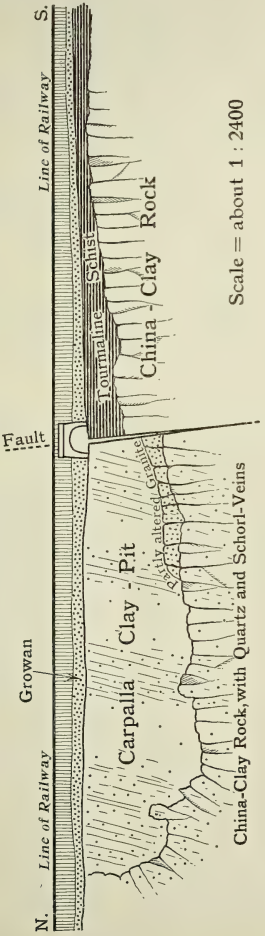


Fig. 2.—*Section of fig. 1 along a line a short distance west of the railway.*

The actual amount of downthrow cannot at present be determined; the pits along the west side of the railway and the great china-clay excavation itself expose more than 50 feet of schist; whence it may be inferred that there has been a downthrow of at least that amount. Ordinarily the fault-fissure is only a few inches wide, and is filled with loose material derived from the walls thereof; but occasionally the filling has been indurated by secondary developments of schorl and quartz, when the two rocks may be seen in juxtaposition. The tourmaline-schist, otherwise lying almost horizontally, is much contorted near the fault. In some places near the fault numerous secondary veinlets of quartz and schorl occur; but farther away the schist is quite free from contortion and veining. Some 30 years ago, when the clay-pit was less than half its present depth, the faulted schist or killas appeared as an almost upright wall bounding its southern side, as shown in the section (fig. 2). On working the clay to a greater depth, it has been found to extend southwards beneath the killas for many fathoms.

The recent investigations have shown that this killas is a nearly isolated patch, as indicated on the accompanying plan (fig. 1, p. 156), having a thickness near corner A of 40 to 50 feet, thinning off at corners B & C, covered everywhere by growan, and resting upon china-clay rock, which is in all respects similar to that exposed in the great clay-pit.

The occurrence of china-clay rock beneath hard and little-altered granite is by no means an uncommon phenomenon in St. Stephen's and the neighbouring parishes, and it has been particularly evident at Central Trevisco; but this occurrence beneath a considerable thickness of schist is, so far, unique. In the clay-pit itself, occasional lenticles or irregular masses of granite in which the felspar is but slightly kaolinized have been met with at various depths. One such lenticle, many square fathoms in area and 5 or 6 feet thick, has been recently observed near the southern side of the pit. This was broken through, and china-clay rock of more than average richness was found beneath it.[1]

As is almost always the case, the great clay-pit shows numerous veins of secondary quartz, sometimes amethystine, or smoky or rosy, and, in most instances, associated with an abundance of schorl. Apart from the thick schistose overburden, there are no geological features at Carpalla that cannot be seen in most of the other clay-works in this part of Cornwall; but this is certainly unique, and it seems to be of vital importance in considering the origin of the clay. The existence of an acre or so of fully kaolinized granite lying beneath 50 or more feet of tourmaline-schist is a phenomenon hitherto unknown in Cornwall, and (I believe) anywhere else.

The pneumatolytic origin of carclazyte has, it appears to me, been sufficiently demonstrated now for nearly a century, and there are few investigators who still doubt that it has been produced by local acid emanations from the main masses of granite.[2]

The active agents in this pneumatolysis may in some instances have included carbonic acid, as has been urged by several geologists of repute, although there is very little positive evidence to support the idea; but, even so, the necessity of abundant emanations containing chlorine, fluorine, and boron at some early stage of the process is obvious enough. Lepidolite is almost always present, gilbertite is frequent, and topaz is by no means rare. Fluorspar occurs in considerable abundance in the china-stone quarries of St. Stephen's and St. Dennis, and schorl is everywhere abundant; and so briefly we may say that fluorine and boron are always present in considerable quantities. To me, therefore, the evidence seems overwhelming, even more so than it did thirty years ago,[3]

[1] [Since the reading of this paper, a vein of greisen containing cassiterite has been found in the 'clay-rock' beneath the capping of tourmaline-schist.—*J. H. C., March 24th, 1909.*]

[2] Those geologists who think that the West of England china-clay 'deposits' have been formed by atmospheric agencies acting from above have, it seems to me, a 'hard nut to crack' at Carpalla. For they must show how those agencies have operated to great depths through thick masses of tourmaline-schist. Elsewhere in Cornwall, as at Great Beam and Balleswidden, they have to account for the operation of atmospheric agencies to depths of more than 200 fathoms and far below the present sea-level.

[3] 'The Hensbarrow Granite District' Truro, 1878; see also 'Nature & Origin of Clays: the Composition of Kaolinite' Min. Mag. vol. vii (1887) p. 205.

that the principal agents in the kaolinization of the granite have been acid solutions or vapours containing fluorine, boron, and, to a less degree, chlorine.

The sequence of events at Carpalla appears, therefore, to have been somewhat as follows :—

(1) Deposition of fine-grained sediments (killas) in, presumably, Lower Devonian times.

(2) Intrusion of granite.

(3) Alteration of killas into tourmaline-schist, by development of tourmaline between the laminæ. Simultaneous kaolinization locally of the felspars of the granite.

(4) Faulting-down of schists during a period of 'reaction' or local subsidence.

(5) Denudation of surface, so as to remove nearly the whole of the schist resting upon the granite.

(6) Formation of growan subsoil or 'head, and of surface-soil or 'meat-earth.'

EXPLANATION OF PLATE VII.

View of Carpalla china-clay pit, from a photograph taken by Mr. J. H. Coath, of Liskeard, showing the overburden of tourmaline-schist resting on china-clay rock.

Discussion.

Mr. Barrow congratulated the Author on having proved the continuity of the kaolinization of the granite under a killas-roof. The faulting-down of this roof in the manner shown by the diagram was not uncommon; for instance, at Darley Vein, near the Cheese-wring, the roof had been dropped to a depth of about 2000 feet. The dispute as to the nature of true 'kaolinization' of granite was largely due to the misapplication of the word to alkali-felspars that had undergone normal decomposition; these, in most cases, were not kaolinized at all, the mineral produced being white mica. The speaker had examined a large area of granitic rocks in Scotland, and had seen no serious trace of true kaolinization anywhere. During ordinary decomposition the brown mica became altered to chlorite, and if the decomposition-products were washed and examined, that mineral was easily found. But no such chlorite was produced during kaolinization; the process was essentially similar to the alteration of granite to greisen, in which, as Mr. Scrivenor had shown (in the pages of the Society's Journal), all the unstable iron-bearing material was used up in the formation of schorl—a stable mineral. Decomposition usually resulted in the brown staining of the granitic material, as the chlorite was formed; while kaolinization resulted in the production of a snow-white clay (kaolin) disseminated through, or containing the other minerals still left, such as quartz, schorl, white mica, etc. The characteristic product of the decomposition, chlorite, was what was known as a low-temperature mineral; while the characteristic product of the kaolinization was schorl, a high-temperature mineral, and the process was clearly a metamorphic one.

Dr. J. S. Flett said that, since first he saw the geological relationships of the china-clay rock to the granite in the field, he had always been strongly of opinion that the kaolinization of the Cornish granites was in no sense the result of ordinary atmospheric decomposition. This opinion had recently been confirmed by a microscopic study of the St. Austell granite and its various modifications. Three types of pneumatolytic alteration would be recognized :—tourmalinization, greisening, and kaolinization. In the first was seen the formation of tourmaline, in the second of white mica, and in the third of kaolin from the original minerals of the granite. Boric acid was certainly one of the principal agents concerned in the production of schorl-rock ; while fluorine was active in the greisening process. The greisens of the St. Austell granite were often excessively rich in topaz, a fluoriferous mineral. In the china-clay rock topaz and fluorspar frequently occurred in large quantity ; but it seemed very probable that another gas had also been present, and this the speaker thought was probably carbonic acid. Igneous magmas contained that gas in solution, and it was not unreasonable to look for products of its action on the felspar. Slides of the kaolin-rock showed that dense masses of kaolin invaded the felspar along its cleavages and other planes of weakness. The felspar was often completely honeycombed by the process of kaolinization, only small isolated fragments being left, surrounded on all sides by finely crystalline kaolin with some quartz and muscovite. The appearance in the microscopic slides was very different from anything that the speaker had ever seen, in granites which had been exposed only to the ordinary agencies of weathering.

Mr. T. Crook asked the Author upon what evidence he relied for the inference that chlorine had played any considerable part in the pneumatolysis of the Cornish granite. He would like to know whether chlorine had been proved to exist in any minerals which could be safely regarded as direct products of pneumatolytic action in this particular case ; and if so, to what extent.

Dr. J. W. Evans drew attention to the evidence afforded by the kaolin of the presence of a considerable amount of water-vapour among the gases by which the pneumatolytic action was effected. This strongly confirmed the views of those who believed that water of intra-telluric origin ('juvenile water') played a very important part in the Earth's history.

The President (Prof. Sollas) remarked that there seemed to be a general opinion in favour of the formation of kaolin-stocks by pneumatolytic action ; and the Author's observations certainly supported this view. The consequences were very far-reaching : the existence of juvenile waters was indicated, but these, on escaping from the granite, must be richly charged with sodium-salts, probably with sodium-chloride ; and he had lately been led to believe that the presence of sodium-chloride in inland waters, such as the rivers of Bohemia, where ancient salt-deposits were absent, was to be accounted for in some such way. At the same time, it did not follow that kaolinization was not also produced by subaërial agency : in the

Bemrose, Collo.

AY PIT, SHOWING THHINA-CLAY ROCK.

J. H. Coath, Photo.

VIEW OF CARPALLA CHINA-CLAY PIT, SHOWING THE TOURMALINE-SCHIST "OVERBURDEN" RESTING UPON CHINA-CLAY ROCK.

Dublin mountains and in Fiji perfectly white china-clay occurred beneath the turf or other vegetation, and passed downwards into granite by an insensible gradation. The one process was by no means exclusive of the other.

The AUTHOR thanked the Fellows for their general acceptance of his geological conclusions. The details of the problem of kaolinization which had been brought forward by several speakers would form a tempting subject for a chemical dissertation, but one too wide to be dealt with adequately on that occasion. He would, however, remark that, although there were in this region positive evidences in abundance of the operation of vapours containing fluorine, boron, and in a less degree of chlorine, there were no such evidences of the operation of carbonic acid; while, therefore, he did not deny its agency, he could find no ground for affirming it, carbonates being remarkable by their absence.

8. *The* DEPTH *and* SUCCESSION *of the* BOVEY DEPOSITS (DEVON). By ALFRED JOHN JUKES-BROWNE, B.A., F.R.S., F.G.S. (Read January 27th, 1909.)

[Abstract.]

THE total thickness of the Tertiary Beds in the Bovey Basin has never yet been ascertained, because no boring has yet reached the bottom of the basin in which they lie; and no one has yet attempted to make out a stratigraphical succession from the sections exposed in the numerous clay-pits.

Some years ago, however, Messrs. Candy & Co., of the Heathfield Potteries, put down a boring which reached a depth of 526 feet from the surface. Having obtained some particulars concerning the beds traversed by this boring, the Author is able to discuss the succession of the Bovey deposits, so far as they have been explored. The following is a generalized description of the strata seen in the Heathfield pit, and penetrated by the boring from the bottom of that excavation:—

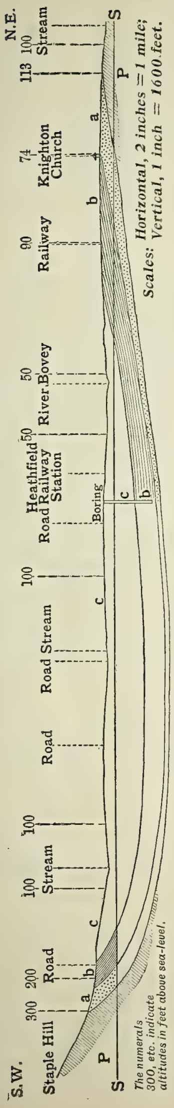
	Thickness in feet.
Superficial deposits .... about	20
Beds of clay and sand, with occasional beds of lignite	250
Beds of lignite and clay, with one of sand	36
Beds of lignite, with thin layers of clay	$220\frac{1}{2}$
	$526\frac{1}{2}$

The Author confirms the conclusion arrived at by Pengelly in 1861, with regard to the relative age of the beds exposed in the 'old coal-pit' south-east of Bovey Tracey and those proved in a boring to the east of it. From all the data mentioned, and assuming the actual base of the Tertiary deposits to be not more than 30 feet below the bottom of the Heathfield boring, he estimates the total thickness of the 'Eocene' beds to be about 613 feet.

The Bovey Basin itself is regarded as a tectonic basin or post-Eocene centrocline, and not as a lake-basin; although, during the deposition of the higher part of the series, it may have formed part of a large lacustrine or lagoon area, extending over the greater part of East Devon.

The Author dissents from Heer's view of the manner in which the lignites were formed, discusses the identification of some of the plants, and concludes that the lignites which form the mass of the lower beds represent the growth and decay of successive swamp-forests, similar to that of the Great Dismal Swamp of Virginia at the present day.

Section across the middle of the Bovey Basin.



[c=Argillaceous series; b=Lignitic series; a=Basal sands; P=Palæozoic.]

Assuming that these lower beds are of Eocene age, and contemporaneous with the Bournemouth Beds of the Hampshire Basin, the Author points out that nothing has yet been proved with regard to the higher beds, which may be of Bartonian, or even of Oligocene age.

Discussion.

Mr. E. A. Martin desired to know whether the re-naming of the flora of the Bovey Beds was thought to carry with it any possibility of a later classification than that of Oligocene.

Mr. J. Allen Howe remarked that there seemed to be much more said in the paper about 'dismal swamp' than about the stratigraphical facts of the Bovey Basin, and pointed out that direct evidence of the disappearance of the 'Eocene' gravel beneath the clays and lignites was not clearly shown at either end of the section exhibited; and, as for the intermediate portion, there was absolutely no evidence whatever, for the Heathfield boring did not penetrate through the lignites into any underlying gravels.

The speaker wished to emphasize his view that the disappearance of the 'marginal' gravels beneath the clays, etc. had nowhere been conclusively demonstrated; and that the omission to pay due attention to the irregular overlying layer of gravel—exactly similar in lithological characters—although it facilitated the construction of certain theories, gave an erroneous aspect of simplicity to the problem.

The speaker thought it a pity to construct a section of this kind, making everything look so regular and orderly, when, as a matter of fact, the individual beds of clay, sand, and lignite were (so far as could be made out) decidedly lenticular and inconstant. Moreover, although the diagram no doubt represented correctly the generalized section of the beds at the site of the Heathfield boring, it was hardly correct to make it apply to the whole

of the basin; for one had to go but a short distance to the eastern side of the basin, to find quite different conditions. The eastern outcrop of the good clays ran for some distance almost due north and south, with a strong westerly dip; but, towards the northern end, the outcrops became less regular, and began to curve slightly westwards south of Knighton. The order of the beds on the eastern outcrop was, from east to west: (1) white pipe-clays; (2) a more sandy and variable set of beds, the so-called 'Betwixt & between Clays'; and (3) best dark clays, followed by more lignitic beds—that was to say, an entirely different sequence from that shown in the section.

The Author regarded the Bovey Basin as a tectonic one, and the speaker was not in a position to disprove this view; nevertheless, there did not seem to be sufficient evidence for it in the paper. If the Eocene gravels on the Haldon Hills, the supposititious gravels beneath the clays, and those flanking the marginal hills were really of the same age, it involved a displacement in the middle of the basin of some 1300 to 1400 feet, or a fall of at least 260 feet per mile. The portion of the basin south of Newton Abbot was not shown in the map upon the screen; but this portion was of great importance: for, if the theory were correct, it would mean a displacement involving a fall of at least 540 feet per mile in the neighbourhood of Aller Vale and Milber Down. Here and at Wolborough, etc. the marginal gravels—which, it would be remembered, were formerly classed as Greensand—clearly followed the existing contours of the hills in a way that was difficult to reconcile with a simple tectonic basin of the kind indicated by the Author; for these rocks could hardly have been folded down in the manner described, without showing some corresponding effects in the underlying Permian or Devonian.

The speaker referred to the very similar though smaller basin in North Devon, between Marland and Petrockstow, south of Torrington: it lay in the bend formed by the upper and lower courses of the Torridge. Here the nature of the materials and their mode of deposition were remarkably like the Bovey Beds: the coarse sands lay on the western side, and the finer white clays and sands cropped out on the eastern side; while the more lignitic beds lay at the northern end.

The PRESIDENT (Prof. SOLLAS) felt sure that the Society joined with him in regretting the enforced absence of the Author. The paper afforded a new and welcome light on an obscure subject. In requesting Mr. Whitaker to reply on behalf of the Author, he would ask him to explain further the evidence on which this illustrative section was based.

Mr. WHITAKER, in answer to Mr. Martin, said that the Author did not propose any new classification of the Bovey Beds.

In answer to Mr. Howe, he said that, while there might be some dearth of evidence, the Author had to make the best of what evidence there was, and this, he thought, had been done. Further evidence would be furnished by additional deep borings; but it seemed unlikely that such would be made. As regarded the section across

the Basin, he himself was disposed to think that the gravel and sand, shown at the base of the deposits, did not continue underground (and, as the Author said, there was no direct evidence of this gravel underlying the clayey beds anywhere); but this was of no consequence in regard to the question of how the beds lay in the Basin. It seemed to him that there was no difficulty in the view that the beds rose up gradually to the level of the Haldon Hills: this needed no great angle of rise, and such rises occurred in other well-known tectonic basins.

Postscript to the Discussion.

[In further reply to Mr. Howe, the Author has communicated the following remarks:—'The diagrammatic section exhibited at the meeting and referred to by Mr. Howe was found to be an incorrect copy of the Author's original drawing, and was so coloured as to convey an erroneous idea of the succession. With regard to the existence of other gravels overlying the Bovey deposits, besides those which appear to pass beneath them, it is evident that Mr. Howe had not realized that this was fully admitted in the paper. The basal beds exposed near Staple Hill, on the south-west side of the basin, are not gravels but sands, which at the very base contain flints, stones, and blocks of chert like those on Haldon. There is also much sand as well as gravel on the eastern border above the level of the plain. The superficial deposits on the plain itself are mostly of a different character: some of these may be of Pliocene and some of Pleistocene age. The Author regards the area south of Newton as a separate subsidiary basin, as explained in his paper on the "Origin of the Plateaus around Torquay" Quart. Journ. Geol. Soc. vol. lxiii (1907) p. 115.'—*February 8th, 1909.*]

9. Palæolithic Implements, *etc. from* Hackpen Hill, Winterbourne Bassett, *and* Knowle Farm Pit (Wiltshire). By the Rev. Henry George Ommanney Kendall, M.A. (Communicated by W. Whitaker, B.A., F.R.S., F.G.S. Read February 24th, 1909.)

[Abstract.]

Implements are described from the localities mentioned in the title, which lie at heights of 885, 576, and 450 feet above O.D. respectively. Hackpen Hill forms a ridge of Chalk running north and south, capped by patches of Tertiary clay. Trimmed stones of eolithic nature were obtained from fields ploughed in Drift-gravels, together with abraded Upper Greensand chert, quartzite-pebbles, and small flints. The greater number of the flaked stones were found within and near shallow pits excavated in yellow Drift-clay, apparently newer than the Red Clay with Flints, exposed at the edges of the larger hollows. The implements are unabraded, abraded, and striated; some stained brown, some green, others unstained; evidently some are *in situ*, others were brought with the Drift. Implements taken from the clay are described, and a distinction is made between the palæoliths and neoliths obtained from the same surface. The similarity in the mineral condition of the former to palæoliths from Knowle Farm Pit is pointed out, and both are referred to the Chelléen period.

It is noteworthy that, while implements and flakes are numerous on the top of Hackpen Hill as compared with good, trimmed pieces, yet at this 570-foot level on the Winterbourne-Bassett plain implements and flakes are very scarce, while trimmed pieces are very numerous, although the level of the Winterbourne stones is 300 feet lower. Many of the latter, however, have been evidently rechipped, and are therefore of later date. The Author concludes that implements of at least three palæolithic periods are found at Knowle, and these three periods may be compared with the Chelléen, Lower Acheulien, and Upper Acheulien of Prof. Commont at St. Acheul. Still older implements (possibly earlier Chelléen) seem also to occur.

Discussion.

Mr. H. W. Monckton asked in what sense the term eolithic was used by the Author. Did the Author treat the eolithic implements as belonging to an older period than the palæolithic implements, or did he use the word as describing a different and ruder form of implement without reference to the period to which it belonged? The speaker mentioned that, in the Reading District, the older implements were, in at least one case, better formed than those of a somewhat more recent date, both being of palæolithic

age (see Ll. Treacher, 'On the Occurrence of Stone-Implements in the Thames Valley between Reading and Maidenhead,' in 'Man' for 1904, No. 10).

Mr. W. Johnson thought that the Author, in carefully classifying the implements according to the levels at which they were discovered, was following a sound principle. The observations, however, would have had enhanced value, if the bottom of the existing valley, rather than the sea-level, were taken as the base from which the heights were measured. The use of the term eolithic, apparently in M. Rutot's sense, as indicating a phase of lithic culture, instead of a definite archæological period, was confusing and regrettable. M. Rutot had actually claimed one such phase, the Flenusien, as existing in the neolithic period. It was true that very rude implements, suggestive of eoliths, were found on the North Downs; but, apart from their being surface-relics, it was doubtful whether, like eoliths, they could be assigned to a few definite groups. The occurrence, at low levels, of implements rougher than those of the older terraces was no new problem. The Solutréen implements of the Cave Period were often of finer workmanship than those of the succeeding Magdalénien epoch. But, in paying close attention to stratigraphy and to types, workers like the Author would, by careful classification, greatly assist the geologist. Recently, Mr. William Wright had discovered palæoliths in excavations at Clapham Common. The gravels of Wimbledon Common, however, different in level and in composition, had as yet furnished no such records. It was in such cases that discoveries and grouping by types might help in determining the relative ages of the beds.

Mr. Hazzledine Warren referred to the difficulty of the problem which was suggested by the series of flints placed upon the table. It was not always easy to discriminate between the real workmanship of man and the simulation of such workmanship which might be produced by natural causes. There was a serious danger of drawing upon the imagination when insufficient attention was given to the experimental investigation of the physical properties of flint, and its behaviour under the various stresses which may act upon it through the operation of natural forces. It was astonishing how easily the characteristic eolithic notches, and the parallel chipping of the edges, could be produced by the mere pressure of one flint against another. Such pressure might be supplied in many different ways, but especially by the movement or creep of superficial deposits.

With reference to the classification of the palæolithic tools, the speaker said that this appeared, in his opinion, to be generally sound. Some were described as pre-Chelléen; he would be sorry to say that this was not the case, but at the same time he thought that further evidence was desirable. Many of the typical examples of the Chelléen series from Chelles itself were extremely rude and primitive, and much resembled those described here as pre-Chelléen.

Mr. Whitaker, in answer to remarks that had been made, agreed that the Author used the term eolithic for a class of implement rather than for a geological period; but this was a legitimate use. There were other cases than that near Reading where the implements of a lower and newer terrace were of a ruder kind than those of a higher and older one. He had himself suggested that it was not height above the sea that should be chiefly considered, in regard to the age of gravels, etc., but height above the neighbouring ground. While he was not disposed to accept all the specimens exhibited as worked, he felt that it was very satisfactory to have a good local observer making these finds in places where implements had not been found before.

10. *The* RELATION *of the* ORDOVICIAN *and* SILURIAN ROCKS *of* CONWAY (NORTH WALES). By GERTRUDE L. ELLES, D.Sc. (Communicated by Dr. J. E. MARR, F.R.S., F.G.S. Read January 27th, 1909.)

[PLATE VIII—MAP & SECTION.]

CONTENTS.

I. INTRODUCTION AND LITERATURE.

THE area constituting the Conway District, for the present purpose, extends from the mountains of Penmaenbach and Dinas on the west, southwards as far as Derwendêg, and thence eastwards to the Conway River, thus including Conway Mountain, and the whole of the country lying immediately north, south-west, and south of the town of Conway itself. On the east side of the estuary there is also the area lying east, north-east, and south-east of the village of Deganwy.

Literature.

The region has not hitherto been worked in any detail, wherefore the literature as a whole is scanty and the information somewhat unsatisfactory. The volcanic rocks have received the greatest share of attention, some of the rhyolites, and especially the nodular rhyolites, having been described by Prof. Bonney, Mr. Harker, Prof. Grenville Cole, and others; but the sedimentary rocks have rarely received more than a general notice.

The more important papers referring to the district are the following:—

(A) Stratigraphical.

Jukes,[1] in his 'Letters,' makes several references to the district; of these the most important statement seems to be that where he

[1] 'Letters & Extracts, &c.' [edited by Mrs. Browne] 1871, p. 440.

refers to Conway Castle as standing

'on the very top of the Bala Beds, somewhere about where the Hirnant Limestone ought to be.'

Unfortunately, he afterwards accepted the view that the rock in question was the equivalent of the Bala Limestone.[1] In the light of recent work, his earlier opinion would seem to be more correct.

Prof. Lapworth,[2] in his classical work on the 'Geological Distribution of the Rhabdophora,' records the existence of graptolites in the Tarannon Shales of the district; he also gives reasons for believing that the beds containing them correspond with the Lower Gala Group of the South of Scotland.

In the second edition of the Geological Survey Memoir of North Wales (1881) pp. 280 *et seqq.*, the succession of rocks at Conway is tabulated. The Llandovery Beds are said to be absent, and the Tarannon Shales are supposed to rest by unconformable overlap upon beds not much higher than the Bala Limestone; they are also stated to form a narrow band at the base of the Denbighshire Grits, from Conway to Llanbedr, a distance of 5 miles. The Denbighshire Grits are estimated as 3000 feet thick; and in the Appendix, certain black shales are regarded as having a Llandeilo fauna, but their relation to the Bala Beds is therefore regarded as being abnormal—they are said to be 'altogether bounded by faults.' The main faults of the district, namely, those of Penmaenbach and the Conway estuary, are also referred to.

In 1896 [3] a short paper was published, in which the discovery in the district of beds of Upper Bala (Ashgillian) and Upper Llandovery age was recorded.

(B) Petrological.

In the Survey Memoir [4] there are a few references to the Conway Mountain Lavas, including the so-called 'nodular felsites'; and a brief description is given of the Penmaenbach rock, which is termed a 'felspathic porphyry.'

In 1882 Prof. Bonney,[5] in a general paper on 'Nodular Felsites in the Bala Group of North Wales,' refers both to the nodular rocks of the Conway District and to some of the other lavas. A brief description of the Penmaenbach rock is also given.

In 1885 Frank Rutley, in the Geological Survey Memoir on the 'Felsitic Lavas of North Wales' (p. 17), described one of the typical lavas from Conway Mountain.

[1] 'Letters & Extracts, &c.' 1871, p. 440, footnote.
[2] Ann. & Mag. Nat. Hist. ser. 5, vols. v & vi (1880) pp. 45, &c.
[3] G. L. Elles & E. M. R. Wood, Quart. Journ. Geol. Soc. vol. lii, p. 273.
[4] 'The Geology of North Wales' Mem. Geol. Surv. 2nd ed. (1881) p. 137.
[5] Quart. Journ. Geol. Soc. vol. xxxviii, p. 293.

The most recent references appear to be those in Mr. Harker's work on the 'Bala Volcanic Series of Caernarvonshire' (1889). He seems to be the first to have drawn attention to the fact that the rocks lying west of the Penmaenbach Fault are not all intrusive, as the 1-inch Geological Survey map would seem to indicate, but similar in many respects to those found on Conway Mountain itself.

II. Succession of the Beds.

In all these papers no hint is given as to the structure of the country, and up to 1896 the existence of the unconformity between the Ordovician and the Silurian rocks had been generally accepted as a certainty. The discovery of Upper Bala and Upper Llandovery Beds seemed to indicate, however, that this unconformity was at any rate not so great as had been previously supposed, and it seemed advisable that the relationship between the two rock-series should be re-examined and mapped over a wider area. This has now been done, with the result that continuously lower Llandovery Beds have been found; and it has become obvious that in the Conway district, at any rate, the unconformity does not exist. There is, on the contrary, a perfectly unbroken succession from the Volcanic Series to the Denbighshire Grits and Flags: also, as might therefore be expected, the newer beds share every degree of the folding and cleavage of the older rocks, and are indeed at times even more intensely folded.

Detailed mapping has moreover brought to light some interesting facts, which affect the age of the Volcanic Series hitherto regarded as belonging to the Bala. Everywhere succeeding the Ashy Beds, which are the highest members of the Volcanic Series, there is found a belt of black shales containing a rich graptolite-fauna. The fauna of the highest shales is closely comparable with that of the Lower Hartfell Shales of the South of Scotland; but the remaining and greater proportion of the beds contain a characteristic assemblage of Upper Glenkiln graptolites, and must therefore be of Llandeilian age; moreover, the Volcanic Series includes within it a band of shale containing Lower Llandeilo graptolites.

This would seem to indicate that the main Volcanic Series, so far as the Conway district is concerned, must be relegated to the Llandeilian. The view held by the Geological Survey palæontologists in 1881 is correct as regards the age of the Black Shales, although the idea that the shales were out of their proper place in the succession does not seem to be justified.

The Conway succession appears to be as follows:—

Salopian.	Benarth Flags and Grits.		Upper flags & thin grits. Fine shales.	Zone of *Cyrtograptus symmetricus.*
			Massive grits. Lower flags & thin grits. Sandy shales.	Zone of *Monograptus riccartonensis.*
			Calcareous flags, with concretions.	Zone of *Cyrtograptus murchisoni.*
Valentian.	Gyffin Shales (300 feet).		Light-coloured flaggy shales, with black bands.	Zone of *Monograptus crenulatus.*
			Light-coloured shales.	
			Light-coloured shales, with black bands.	Zone of *Monograptus crispus.* Zone of *Rastrites maximus.* Zone of *Monograptus sedgwicki.*
			Grey shales, with soft black mudstone-bands.	Zone of *Monograptus gregarius.*
			Blue-grey iron-stained flags, with softer shaly bands.	Zone of *Mesograptus modestus.*
	Conway Castle Grits (150 feet).		Massive calcareous grits, with shale-bands.	
Ashgillian.	Deganwy Mudstones (*Phacops*-Mudstones) (80 feet).		Blue-grey shales and calcareous mudstones.	Zone of *Phacops* (*Dalmannites*) *mucronatus* and *Dicellograptus anceps.*
	Bodeidda Mudstones (*Trinucleus*-Mudstones) (350 feet).	Upper Lower	Blue-grey and mottled mudstones, with fossiliferous bands.	*Trinucleus*-Beds.
Caradocian.	Cadnant Shales (*Dicranograptus*-Shales) (310 feet).	Upper	Shivery black shales, with a thin ash-band.	Zone of *Dicranogaptus clingani.*
			Black 'blocky' shales.	Zone of *Climacograptus wilsoni (?).*
Llandeilian.		Lower	Hard flaggy shales.	Zone of *Dicranograptus brevicaulis* and *Mesograptus multidens.*
			Flags and shales, with siliceous ashy bands.	Zone of *Climacograptus peltifer.*
Conway Mountain Volcanic Series.	Upper or Coetmor Ash-Group (thickness very variable).		Coarse shaly ashes. Mudstone-band, with *Lingulæ.* Siliceous ashy grits. Mudstone-band. Brecciated rhyolite. Siliceous ashy grits, with nodular rhyolite.	
	Upper Brecciated Lava-Group (710 feet).		Pale creamy rhyolites, with conspicuous flow-brecciation and two well-marked nodular bands near the summit and the base.	
	Lower or Bodlondeb Ash-Group (60 feet).		Coarse and fine ashes and ashy shales, with a shale-band containing *Glyptograptus teretiusculus.*	
	Lower Banded Lava-Group (1400 feet).		Light-grey and greenish-grey rhyolites (?). Dark-grey banded rhyolites (?). Pale-grey banded rhyolites (?).	

[The stated thicknesses are approximate only.]

III. Scenery of the District.

Everywhere the rocks of the Volcanic Series rise abruptly to form rough mountainous land, the summits of which reach 800 feet or more above sea-level; these are generally heather- or gorse-clad, though affording a certain amount of rough pasture-land. There is always a rapid fall of ground where the *Dicranograptus*-Shales succeed the Ashy Grits, and it is to this that the steep slope of the eastern end of Conway Mountain is due. The Bodeidda and Deganwy Mudstones, on the other hand, occupy gently rolling ground for the most part, while a decided feature invariably marks the oncoming of the Conway Castle Grits. The Gyffin Shales, like the *Dicranograptus*-Shales, are usually found in the hollows; but the Benarth Flags and Grits give rise to hilly country with an average elevation of about 400 feet due south of Conway, and this land is usually more wooded than any other part of the district.

IV. Structure of the District.

In the main, the beds of the Conway district form part of a great buckled syncline with a south-south-easterly pitch. A series of 'tear-faults' (Marr), intimately connected with the buckling and resulting from tangential movement, also affect all the beds in the northern part of the area, and the combined effect of the buckling and tear-faulting is well brought out by the outcrop of the Conway Castle Grits. There is a considerable amount of mineralization along some of these tear-faults, and where there is a good rock-face bounding a fault, horizontal slickensiding is sometimes beautifully shown.

The structure of the south-eastern part of the area seems, however, to be somewhat more complicated; there appears to be an important line of disturbance running from Gyffin to Hendre, and though from the nature of the ground it is hard to trace it through the Benarth Woods, there seems to be little room for doubt that it is the same line that comes out on the Benarth shore immediately south of the Point. Everywhere above this line of disturbance the beds are packed together far more closely than they are anywhere below it; anticlines and synclines succeed each other very rapidly, and all show a tendency to overfold northwards.

The apparently simple anticline of Gyffin Shales near Bryn Glorian Mawr is in reality much more crumpled than it has been possible to indicate on the map (Pl. VIII); the general nature of the folding is, however, well displayed along the Benarth shore (see Pl. VIII, section). Here the characteristic features are clearly seen, namely the tendency to overfolding northwards, and the overriding of the upper limb over the lower wherever a fold is broken. It seems, therefore, almost impossible to avoid the conclusion that the Benarth-Gyffin-Hendre line of disturbance is really

Fig. 1.—*Section of the western end of Conway Mountain, on the scale of 8 inches to the mile.* (*See p. 175.*)

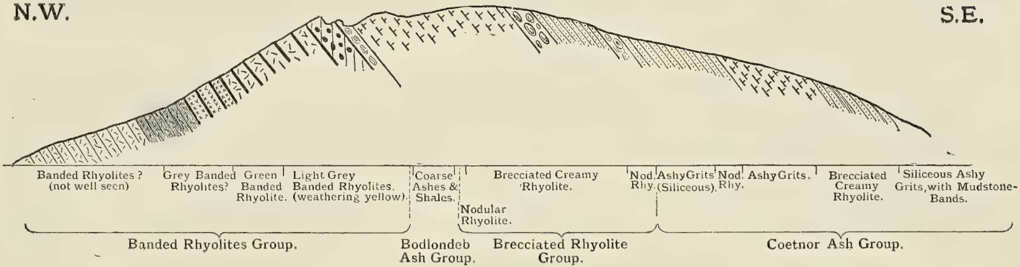
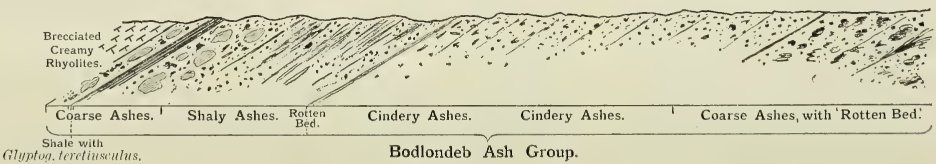


Fig. 2.—*Section of the Bodlondeb Ash-Group, on the scale of 20 feet to the inch.* (*See p. 176.*)



the outcrop of a plane of movement, along which there has been slight thrusting from a southerly direction.

I have been unable to find any evidence of the existence of the long fault which limits the southern slope of Conway Mountain on the 1-inch map, although there is a fault with an east-to-west trend extending from the Sychnant Pass to the Penmaenbach Fault, and more faults with similar trends a little farther south. The Penmaenbach Fault is joined on the south by a most important structural fault, which brings various members of the sedimentary groups against those of the Volcanic Series.

V. Detailed Description of the Beds.

(1) Conway Mountain Volcanic Series.

The Volcanic Series is very thick in the western part of the area, but thins away rapidly when traced eastwards. This is particularly noticeable with the highest and lowest members of the series, the lowest being only seen at the western end of Conway Mountain, while the Coetmor Ash-Group diminishes steadily in an easterly direction, and on the eastern side of the estuary is only a few feet thick. The middle members of the series are, however, somewhat more persistent, the main Nodular Rhyolite being still found on the far side of the estuary, with representatives of the Upper Brecciated Lavas in a much attenuated form.

Conway Mountain.

(A) Lower Banded Rhyolites.—The various members of the Conway Mountain Volcanic Series are best displayed at the western end of the mountain, near the Penmaenbach Fault (fig. 1, p. 174).

The lowest members of the group of Banded Lavas occupy but a small area, and are not well exposed. They consist of greyish banded rhyolites, which acquire a yellowish tinge when weathered: striking north-eastwards, they are soon lost in the direction of Conway Marsh. A short distance above the 200-foot contour-line dark-grey banded rhyolites (?) succeed them, which are now being extensively quarried both for setts and road-metal; above these are some similar but paler rhyolites (?), the uppermost members of which are somewhat flinty and light green in colour, while the flow-banding is indicated by lines of opaque dust. These rocks are well seen between the 300- and 400-foot contours, and have been quarried both on the mountain and on the road after being slightly shifted by a tear-fault: they also disappear under Conway Marsh. The remainder of the hill, nearly up to the small peak on the 700-foot contour-line, is mainly occupied by a series of the pale-grey rhyolites (?) which weather yellow, and are either granular or platy, but are always clearly banded. There are, however, at least

two thin flows near the summit of the hill, which are uniformly darker in tone and show distinct phenocrysts.

(B) Lower or Bodlondeb Ash-Group.—The whole of the top of the hill is occupied by the members of the Bodlondeb Ash-Group, a series of fine and coarse ashes with some shale-bands. The coarser bands contain large fragments of the Banded Lavas and also fragments of shale; these may be well studied close to the Reservoir; traced north-eastwards they are seen to be thrown slightly forward by a tear-fault, and like the whole of the Lower Banded Lava-Group disappear beneath Conway Marsh. This Ash-Group, however, reappears at the northern end of Bodlondeb Wood, where it is well exposed both in the wood and on the path, as well as on the shore below. The section is as follows (fig. 2, p. 174):—

	Thickness in feet	*inches.*
Creamy rhyolites of the Upper Brecciated Group ...	?	
Coarse ash, with shale-fragments	2	0
Shale-band, with *Glyptograptus teretiusculus* (His.) .	1	6
Coarse ash, with large shale-fragments	15	0
Rotten bed	?	
Cindery ashes	27	7
Coarse ashes	9	0
(Base not seen.)		

The ashes here contain fewer and smaller rhyolite-fragments, while the slaty matter is more abundant than on Conway Mountain: it is obvious, therefore, that it is passing away from the source of the volcanic material. This is still further emphasized on the eastern bank of the River Conway, where the members of the group are once more exposed after being faulted back some distance to the north-west. They are best seen on the flanks of the small hill north-east of Castell Deganwy; at this locality the slaty material largely preponderates over the ash, and graptolites are correspondingly more abundant.

This Ash-Group appears to mark the limit between the Lower Banded Rhyolites and the Upper Brecciated Rhyolites: for the greater part of Conway Mountain is occupied by different members of a series of cream-coloured rhyolites, which exhibit flow-brecciation extremely well and are much quartz-veined; they are sometimes platy and occasionally somewhat banded, although never so decidedly as those lavas that belong to the belt below the Bodlondeb Ashes.

(C) Upper Brecciated Rhyolites.—The Upper Group of Lavas are characterized by their creamy colour and flow-brecciation: the lowest members appear to have undergone intense silicification; and among them is a very beautiful nodular rhyolite, with large nodules measuring from 6 to 8 inches in diameter. This band, however, does not exceed 20 feet in thickness; it is well exposed on the northern slope of the mountain, some little distance below the

old quarry-chute. On the southern slope above the main mass of the creamy lavas, another nodular rhyolite is seen close to the summit, and may be traced all along the face of the mountain, though its course is interrupted twice by faults. In this nodular rhyolite the nodules measure generally only 1 or 2 inches in diameter, and the rock passes down imperceptibly into a finer rock, frequently pinkish in colour, which cannot be separated from it. Together these form a band about 50 feet thick. This, the Main Nodular Rhyolite of the district, is seen again at Bodlondeb, and on the Deganwy Hills. (See fig. 3, p. 178.)

The brecciation of the Creamy Rhyolites themselves is often beautifully seen, especially when the fragments of the light-coloured rock are (as it were) cemented together by a black chert-like substance. This is very hard, and must not be confused with the softer black substance which is of frequent occurrence in the nodular bands, and has been referred to by Prof. Bonney,[1] Prof. Cole,[2] and Mr. Harker.[3] Mr. Fearnsides has suggested to me that it may be a product of the rock itself, separated during its alteration; it is often seen filling the joints and minutest interstices of the rock, and is probably quite different in origin from the white crystalline quartz with which the rocks are frequently veined.

(D) Upper or Coetmor-Ash Group.—A few feet only of creamy rhyolites separate the Main Nodular Rhyolite from the Siliceous Ashy Grits which form the basal members of the Upper Ash-Group. These grits are decidedly more felspathic in the western than in the eastern parts of the district. They are very much thicker also in the west, where they contain two definite lava-flows and two mudstone-bands.

Of the two lavas within the group, the lower is another nodular rhyolite, which is very like the Main Nodular Rhyolite; it extends only for a short distance along the southern slope of the mountain. The higher is a typical creamy rhyolite, which occupies a fairly wide tract a little distance south of Conway Mountain proper, and forms a subsidiary hill. It is at once succeeded by the lower of the two mudstone-bands, which is apparently unfossiliferous. The higher band, however, contains numerous *Lingulæ* (*L. attenuata*, Sow.), and the associated ashy grits are much less siliceous and more shaly in character than those at a lower horizon, there being an obvious transition into the overlying *Dicranograptus*-Shales. These shaly grits are exposed on the southern slope of the mountain along the lower path north-east of Bron-lledraeth, and again a little north of Derwendêg; while the actual transition between the highest ashes and the shales is best seen in the north-western end of the Railway-Cutting section.

[1] Quart. Journ. Geol. Soc. vol. xxxviii (1882) p. 294.
[2] *Ibid.* vol. xlii (1886) p. 186.
[3] 'Bala Volcanic Series of Caernarvonshire' 1889, p. 29.

Fig. 3.—*Section through the Deganwy Hills, on the scale of 12 inches to the mile.* *(See p. 177.)*

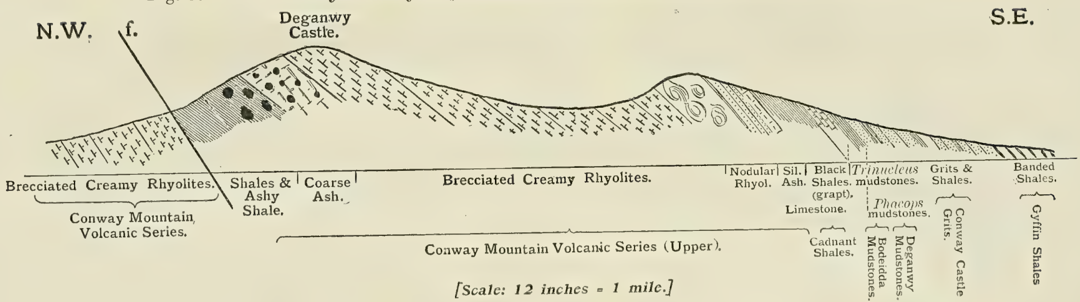
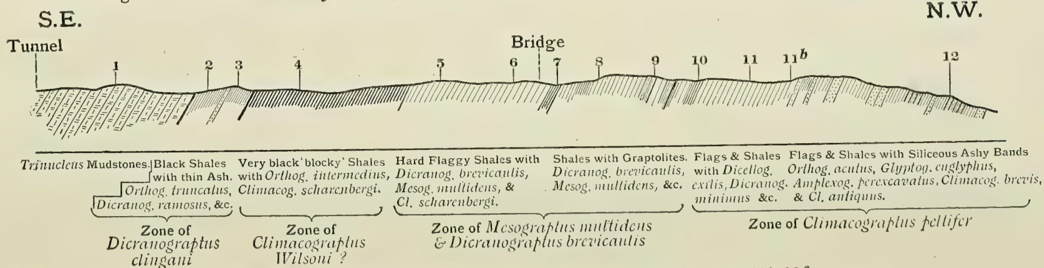


Fig. 4.—*Section in Conway railway-cutting, on the scale of $52\frac{1}{2}$ yards to the inch.* *(See pp. 179–82.)*



[The numerals indicate localities where fossils were obtained: see pp. 180–82.]

Area West of the Penmaenbach Fault.

As noted long ago by Mr. Harker,[1] the ground west of the Penmaenbach Fault does not seem to be occupied by intrusive rock as the 1-inch map would indicate, but is mainly composed of creamy rhyolites. They appear to be very similar in general character to those forming the main mass of Conway Mountain, although they are decidedly thicker and have more mudstones and ash-bands intercalated amongst them. They strike north-north-westwards, and it seems possible to recognize the two Upper Nodular Rhyolites overlain by the Siliceous Ashy Grits. Also, though the mudstone is not well exposed naturally, it is obvious that the reservoir-tank lying close to the Penmaenbach Fault has been excavated in a shaly mudstone-band; and, from the heaps of material lying round about, it was possible, after much searching, to collect and identify a few specimens of *Climacograptus schärenbergi*, Lapw. and *Cl. antiquus*, Lapw.

It does, however, appear that the main mass of Penmaenbach is composed of a different rock, and the mapping suggests that this may be filling a neck. This neck, if neck it be, is now filled with a rock which has many of the characters of a rhyolite, although it differs from the general mass of the rhyolitic lavas of the series. It is most like one of the Lower Banded Rhyolites, but the ground-mass is rather more coarsely crystalline, a fact which may well be accounted for by its mode of occurrence. It is more distinctly porphyritic near its edge, where there also appears to have been greater silicification.[2]

The ground to the west of the Penmaenbach Fault is much faulted, and the lavas are highly silicified, especially as they approach the edge of the neck.

(2) Cadnant or *Dicranograptus*-Shales.

The best exposures of the Cadnant or *Dicranograptus*-Shales are near the town of Conway, in the district known as Cadnant Park; they used also to be well seen at various points near the old copper-mines at Derwendeg, though these are now largely built over.

The best section of all is displayed in the railway-cutting north-west of Conway Station, where the entire thickness of the beds

[1] 'Bala Volcanic Series of Caernarvonshire' 1889, p. 22.

[2] All the lavas have undergone extensive silicification, and though in a rock-slice it is often very difficult, if not impossible, to distinguish between primary and secondary quartz, it is fairly obvious in the field that the silicification is highly intensified in the neighbourhood of the larger faults. The creamy rhyolites become almost like quartzites, and the nodular rhyolites lose much of their conspicuously nodular character, the curved edges of the 'shells' being only discernible in places, and the rock having a very brecciated appearance; as it is traced away from the fault-line, however, it gradually returns to its normal character, only to lose it again as it approaches a second fault. It seems, therefore, fairly clear that some of the alteration is due to silicification along the fault-lines: though much of the alteration is characteristic of the rocks as a whole, and is quite independent of any earth-movements.

is seen, from their junction with the Ashy Grits of the Volcanic Series below, to their passage into the Bodeidda or *Trinucleus*-Mudstones above (see fig. 4, p. 178). The beds are somewhat contorted and slickensided, and dip south-eastwards at a high angle (60° to 80°); they are more or less fossiliferous throughout, although the graptolites appear to be especially abundant in certain bands.

At the base of the section, at its north-western end, are seen mudstones and shales with bands of ashy grits. The shale-bands have yielded *Glyptograptus teretiusculus* (His.), *Mesograptus* cf. *foliaceus* (Murch.)?, *Amplexograptus perexcavatus* (Lapw.), *Climacograptus brevis*, E. & W., *Cl. antiquus*, Lapw., and *Cl. schärenbergi*, Lapw. (=Locality 12: the locality-numbers correspond to those indicated in fig. 4.) The ash-beds then become thinner and less important, finally disappearing, and the next highest beds seen are a series of shales which contain the following fossils (Locality 11*b*):—

Mesograptus multidens, Elles & Wood.
Orthograptus acutus, E. & W.
Glyptograptus teretiusculus, var. *euglyphus* (Lapw.).
Amplexograptus perexcavatus (Lapw.).
Climacograptus antiquus, Lapw.
Dicranograptus brevicaulis, E. & W.

At a slightly higher horizon there occur (Locality 11):—

Glyptograptus teretiusculus (His.) and var. *euglyphus* (Lapw.).
Mesograptus multidens, E. & W.
Amplexograptus perexcavatus (Lapw.).
Climacograptus schärenbergi, Lapw.

While still higher (at Locality 10) the beds are richly fossiliferous, and have yielded:—

Dicranograptus brevicaulis, E. & W.
Dicellograptus sextans, var. *exilis*, E. & W.
Dicranograptus furcatus, var. *minimus*, Lapw.
Climacograptus schärenbergi, Lapw.
Mesograptus multidens, E. & W.

The general aspect of this fauna strongly recalls that of the higher parts of the Glenkiln Shales of the South of Scotland; it is probable, therefore, that the beds represent the Zone of *Climacograptus peltifer*. It is worthy of note that, while both *Mesograptus multidens* and *Dicranograptus brevicaulis* are present, they are comparatively rare when contrasted with the abundance of the *Climacograpti*.

Flags and shales of similar lithological character succeed, and have yielded the following faunas:—

At Locality 9:

Mesograptus multidens, E. & W. (abundant).
Glyptograptus teretiusculus, var. *euglyphus* (Lapw.).
Amplexograptus perexcavatus (Lapw.).

At Locality 8:

Mesograptus multidens, E. & W.
Climacograptus schärenbergi, Lapw.
Amplexograptus perexcavatus (Lapw.).

At Locality 7:

Dicranograptus brevicaulis, E, & W. (abundant).
Mesograptus multidens, E. & W. (abundant), and var. *compactus*, E. & W.
Climacograptus bicornis, Hall.
Climacograptus antiquus, var. *lineatus*, E. & W.
Climacograptus schärenbergi, Lapw.
Thysanograptus harknessi (Lapw.).

At Locality 6:

Dicranograptus brevicaulis, E. & W.
Mesograptus multidens, E. & W.
Thysanograptus harknessi (Lapw.).

At Locality 5 *Orthograptus calcaratus* var. *vulgatus*, E. & W., is abundant, with rarer *Dicranograptus brevicaulis* and *Mesograptus multidens*.

All these flags and shales, including localities 9–5, may be termed the Zone of *Mesograptus multidens* and *Dicranograptus brevicaulis*, since both these fossils are characteristic forms throughout.

Black 'blocky' shales then succeed, the fauna of which differs from that just described, mainly in the abundance of *Orthograptus truncatus* var. *intermedius*, E. & W. Other common graptolites are *Orthograptus vulgatus*, E. & W., *Glyptograptus euglyphus* (Lapw.), and *Climacograptus schärenbergi*, Lapw. These beds are fairly thick; but, towards the end of the section, they give place to soft black shivery shales (weathering orange), which contain a very different fauna, namely:—

At Locality 3:

Abundant *Orthograptus truncatus* (Lapw.).

And at Locality 2:

Dicranograptus nicholsoni, Hopk.
Dicranograptus ramosus, Hall.
Climacograptus bicornis, Hall.
Climacograptus minimus, Carr.
Orthograptus truncatus (Lapw.).

The incoming of *Orthograptus truncatus* is characteristic of the Zone of *Dicranograptus clingani*, and the other graptolites are all forms commonly associated with it. It seems, therefore, fairly clear that these beds represent that horizon, while the black blocky shales immediately below must, I think, represent the Zone of *Climacograptus wilsoni*, which is commonly characterized by the presence of *Orthograptus truncatus* var. *intermedius*, here the most abundant species.

These shivery shales are at once succeeded, without any break, by the Bodeidda Mudstones, with their characteristic *Trinucleus*-fauna; from Locality 1, in addition to remains of *Trinucleus*, there was obtained the tail of a large Asaphid (possibly *Asaphus radiatus* or *A. nobilis*).

These same black *Dicranograptus*-Shales are also seen east of the river, in a much attenuated form. At the base there, they have a distinct limestone-band, full of the remains of large brachiopoda;

these have been obtained from three different localities along the southern slopes of the Deganwy Hills. The fauna from this limestone includes

[1] *Orthis calligramma*, Dalm.	*Orthis vespertilio*, Sow. ?
Orthis plicata, Sow.	*Orthis* sp.
Orthis (Dinorthis) flabellulum, Sow., var.	*Strophomena* aff. *medicostalis*, Reed.
	Strophomena corrugatella, Dav.

(3) Bodeidda or *Trinucleus*-Mudstones.

These mudstones, as their name implies, are best seen near Bodeidda, a mile and a half south-west of Conway, where there are several good sections in quarries and along the road. The rocks are generally blue-grey mudstones weathering light brown, while some bands have a characteristic mottled appearance. Some of the bands appear to be quite unfossiliferous, but in others fossils are abundant. The following are common:—

Trinucleus seticornis, var. *bucklandi*, Barr.	*Orthis (Dalmanella) elegantula*, Dalm.
Cybele.	*Orthis (Heterorthis) retrorsistria*, M'Coy.
Plectambonites transversalis (Wahl.).	*Tentaculites anglicus*, Salt.
Plectambonites quinquecostata (M'Coy).	

These exposures are mostly in the lower beds; the higher beds are better seen in an old brick-pit, close to where the footpath to Oakwood Park Hotel leaves the Sychnant road, about three quarters of a mile west of Conway. Here the beds contain a somewhat similar assemblage of forms; but *Christiania tenuicincta* is especially abundant, and the *Trinuclei* are rather different.

Trinucleus concentricus, var. *portlocki*, Salt., and var. *arcuatus*, Smith.	*Plectambonites transversalis* (Wahl.).
Phacops (Acaste) brongniarti (?) Portl.	*Plectambonites quinquecostata* (M'Coy).
Calymene blumenbachii, Brongn.	*Christiania tenuicincta* (M'Coy).
Orthis (Dalmanella) elegantula, Dalm.	

These mudstones are also exposed in the fields north of Maes Cadwgan and all round Bryn Bychan; also at many places in the streets of Conway and on the shore north of the Castle, where they are succeeded by the Deganwy or *Phacops*-Mudstones and the Conway Castle Grits. They are also well seen in a similar position, north of the Bryniau Watch-Tower, on the Deganwy side of the river.

(4) Deganwy or *Phacops*-Mudstones.

Between the fossiliferous *Trinucleus*-Mudstones and the *Phacops*-Mudstones intervenes a thin band of light-coloured mudstone, which appears to be wholly destitute of fossils; this is seen on the road south-east of Bryn Hendre, and the rest of the road down to the village of Hendre is cut out in the fossiliferous mudstones with *Phacops (Dalmannites) mucronatus*, Brongn., until these are succeeded by the Conway Castle Grit.

[1] For these and other identifications of brachiopods I am indebted to Mr. F. R. C. Reed.

These *Phacops*-Mudstones are also seen at various other localities beneath the grit; especially in the big quarry north of Bryn Seriol, close to Conway, where the grits have been quarried away close to the mudstones: these are left as a long wall on the north-eastern face, various specimens of *Phacops (Dalmannites) mucronatus* being visible on the weathered surface. The mudstones are seen again on the Gyffin road immediately below Conway Castle, where, in the associated shales, several specimens of *Orthograptus truncatus* var. *abbreviatus*, E. & W., were found: this is a characteristic fossil of the Zone of *Dicellograptus anceps*. Best of all, however, are these beds displayed in the large quarry on the southern slope of the Deganwy Hills, whence they derive their name, and where, immediately beneath the grits, a series of shales and mudstones is exposed. In a band in the lowest shales *Orthograptus truncatus* var. *abbreviatus* was again found, beautifully preserved and in fair abundance; 7 feet above this band is a bed of brownish calcareous mudstone which yields abundant remains of huge specimens of *Phacops* (*Dalmannites*) *mucronatus*, Brongn., and, in addition, such forms as

Orthoceras vagans, Salt.
Orthoceras sp.
Orthis (Dalmanella) elegantula, Dalm.
Orthis sp.
Chonetes lævigata, Sow.
Holopella.
Cleidophorus planulatus (?) Conr.
Ctenodonta varicosa, Salt.
Theca (?).
Tentaculites anglicus, Salt.

In the 5 feet of mudstone intervening between the calcareous bed and the grits, numerous specimens of the *Phacops*, but of smaller size, may be found.

(5) Conway Castle Grit.

The Conway Castle Grit is the highly calcareous grit upon which Conway Castle is built, and which Jukes at one time correctly considered to be the equivalent of the Hirnant Limestone. It always makes a feature wherever it occurs, and its outcrop brings out the structure of the country very clearly. In the western part of the district it is folded into two synclines with an anticline in between, although the actual outcrop appears to be concealed by overthrusting; it is then faulted three times in quick succession in the immediate neighbourhood of Conway, and again along the line of the estuary. The grit is by no means uniform in character; it is thickest and coarsest on the Deganwy side of the river, where the massive grit-beds are separated by flags with thin grits among them (see fig. 5, p. 184). In the big quarries at Deganwy and Bryniau the following fossils have been obtained from the higher beds:—

Deganwy.

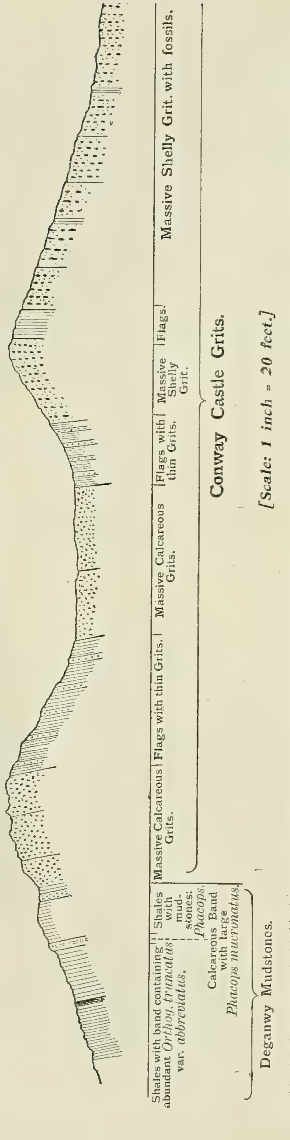
Orthis hirnantensis, M'Coy.
Christiania tenuicincta (M'Coy).
Petraia subduplicata, M'Coy.
Fragments of corals and crinoids.

Bryniau.

Orthis hirnantensis, M'Coy.
Orthis calligramma, Sow., var.
Orthis (Dalmanella) elegantula, Dalm.
Streptelasma sp.
Petraia subduplicata, M'Coy.
Favosites cf. *gothlandica*, Fougt.
Crinoid-stems and fragments of corals.

Fig. 5.—*Section in Deganwy Quarry, on the scale of 20 feet to the inch.* (*See p. 183.*)

N.W. S.E.



This fauna agrees well with that of the Hirnant Limestone. Traced in a southerly direction, this calcareous grit becomes much finer in grain, and flaggy beds are increasingly prominent among gritty bands. It seems almost certain that the thick series of fossiliferous flags with some gritty bands exposed at Bryn Dowsi represents actually part of the grit itself as seen below Conway Castle; and since these beds contain a characteristic Lower Llandovery graptolite-fauna, it would appear that the upper part of the grit at any rate (if not the whole) should really be regarded as of Llandovery age.

(6) Gyffin Shales.

The Gyffin Shales, which must occupy the bed of the Afon Gyffin for a considerable part of its course, occur in more or less isolated exposures, except immediately south of Conway, since they are only seen in the cores of the folds. With the exception of the lowest members, which are flaggy, the beds consist for the most part of a series of pale-grey pasty mudstones or shales with very thin, soft, black bands containing graptolites; the beds are always much cleaved, and it is often impossible to obtain recognizable fossils from poor exposures, so that it is not always possible to distinguish between Llandovery and Tarannon rocks. That both series are, however, completely represented becomes perfectly obvious when the fossils obtained from all the different exposures are studied together.

The lowest beds, a series of flags and shales, with some harder gritty bands, are seen along a road-section behind Bryn Dowsi, where they are full of *Mesograptus modestus* (Lapw.), *Climacograptus normalis*, Lapw., *Cl. rectangularis*, M'Coy; and in the higher bands *Monograptus incommodus*, Törnq., comes in. These are clearly the *Mesograptus-modestus* Flags of other areas. They are seen to be succeeded at once by higher shales in the small quarry north-west of the farm; the beds are somewhat disturbed here by the proximity of the fault, but have yielded an unmistakable assemblage of graptolites, namely:—

Climacograptus rectangularis, M'Coy.	*Monograptus revolutus*, Kurck.
Climacograptus hughesii (Nich.).	*Monograptus fimbriatus*, Lapw.
Glyptograptus tamariscus (Nich.).	*Monograptus lobiferus*, M'Coy.

These clearly indicate the beds to be on the horizon of the lower part of the Zone of *Monograptus gregarius*, Lapw.

The lower beds are again seen on the roadway due north of Pont Gyffin (1), where they are, however, much thinner; and the higher beds come up in a crumpled anticline, in a small quarry south-west of Bryn Glorian Mawr (2), and in the wood to the north-west (3). Here I have collected:—

(1) Pont Gyffin.

Mesograptus modestus (Lapw.).	*Climacograptus hughesii* (Nich.).
Climacograptus normalis, Lapw.	*Glyptograptus persculptus* (Salt.).
Climacograptus rectangularis, M'Coy.	

(2) South-west of Bryn Glorian Mawr.

Rastrites peregrinus, Barr.	*Monograptus lobiferus*, M'Coy.
Monograptus fimbriatus, Lapw.	*Monograptus triangulatus* (Hark.).
Monograptus gregarius, Lapw.	*Glyptograptus tamariscus* (Nich.).
Monograptus attenuatus, Hopk.	*Climacograptus scalaris*, His.
Monograptus jaculum (?) Lapw.	*Climacograptus hughesii* (Nich.).
Monograptus communis, Lapw.	

(3) Wood north of Bryn Glorian Mawr.

Rastrites peregrinus, Barr.	*Monograptus triangulatus*, Hark.
Monograptus attenuatus, Hopk.	*Monograptus jaculum (?)* Lapw.
Monograptus communis, Lapw.	*Climacograptus hughesii* (Nich.).

The only locality known to me where the Zone of *Monograptus sedgwicki* is exposed, is at the mouth of the Afon Gyffin, due north of the Lodge at the entrance to Benarth; here certain rocks, which are only exposed at the lowest spring-tides, yielded numerous examples of *Monograptus sedgwicki* itself, with some Diplograptidæ, and I believe represent that zone. The succeeding beds of the Zone of *Rastrites maximus* are to be seen in the river-bank beyond the timber-yard a little farther west (i), and also in the bank behind the timber-stacks at the corner of the Gyffin road (ii).

The commonest forms at these localities are the following :—

[1] (i) River-Bank.	[1] (ii) Marsh.
Rastrites maximus, Carr.	*Rastrites maximus*, Carr.
Monograptus turriculatus, Barr.	*Monograptus turriculatus*, Barr.
Monograptus halli, Barr.	*Monograptus becki*, Barr.
Monograptus becki, Barr.	*Monograptus pandus*, Lapw.
Monograptus gemmatus, Barr.	*Monograptus halli*, Barr.
Monograptus cf. *speciosus (?)* Tullb.	*Monograptus galaensis*, Lapw.
Monograptus nudus, Lapw.	*Monograptus nudus*, Lapw.
Monograptus rigidus, Lapw.	*Monograptus rigidus*, Lapw.
Climacograptus extremus, H. Lapw.	*Monograptus runcinatus*, Lapw.

The beds belonging to the Zone of *Monograptus crispus* are best seen exactly opposite the Castle, on the road leading to Benarth: they have yielded the following graptolites in some abundance :—

Monograptus crispus, Lapw.	*Monograptus* cf. *dextrorsus*, Tullb.
Monograptus exiguus, Nich.	*Monograptus marri*, Perner.
Monograptus turriculatus, Barr.	*Monograptus galaensis*, Lapw.
Monograptus nodifer, Tullb.	*Petalograptus palmus*, Barr.
Monograptus gemmatus, Barr.	*Petalograptus* cf. *ovatus*, Barr.
Monograptus rigidus, Lapw.	

Descending to the shore from the road, it is clearly seen that these beds are succeeded by a belt of pale shales, which appear to have no black bands and to be unfossiliferous; but close below the commencement of Benarth Wood black bands come in again, and have yielded the characteristic graptolites of the Zone of *Monograptus crenulatus*. These beds become flaggy towards the top, and seem to constitute a passage into the overlying Benarth Flags and Grits.

(7) Benarth Flags and Grits.

The Benarth Flags and Grits are best displayed along Benarth shore, on the west side of the River Conway, where they immediately succeed the highest members of the Gyffin Shales. The structure of this part of the country is clearly brought out when mapped on the 25-inch scale; but inland the exposures are not sufficiently good to render it possible to plot all the folds with the same certainty. The beds are sharply folded for the most part in a series of steep isoclines, although these are not perfectly uniform, owing to the fact that the grits have 'held' better than the flags; there are, in addition, a few minor faults (? thrusts).

Immediately above the highest Gyffin Shales are seen a series of flaggy beds with calcareous concretions; these beds are exposed for about 200 yards, and yield plentiful examples of *Cyrtograptus murchisoni*, Carr., *Monograptus vomerinus*, Nich., *M. priodon* Bronn., and *Gladiograptus geinitzianus*, Barr.; it is, therefore, perfectly

[1] These exposures are not now so workable, as at the time when Mrs. Shakespear (Miss E. M. R. Wood) and I first came to the district. The above lists have been drawn up mainly from our earlier collections, and are revised up to date.

obvious that they represent the Zone of *Cyrtograptus murchisoni*, the characteristic zone of the base of the Wenlock. They are succeeded by sandy shales with *Monograptus riccartonensis*, Lapw. as the most abundant fossil. A small thrust separates these from the next highest beds, flags with few grits, which also contain *M. riccartonensis*; cone-in-cone structure is shown in places, and the same beds are continued up to the Point, where massive grits overlie them.

Beyond the Point where the massive grits come on, and where the Hendre-Gyffin-Benarth line of disturbance affects the succession, the beds are sharply bent into a series of isoclinal folds of various dimensions, causing a deceptive appearance of thickness at first sight. It is worthy of notice that the minor faults (? thrusts) affecting the beds, which are all much compressed, invariably occupy the crests of the anticlines.

The massive grits beyond the Point are sharply folded and broken, while between the Point and the Old Limekiln the section shows a series of flags and grits which still contain *Monograptus riccartonensis*; in places, however, higher beds comprising fine shales which weather to a bright orange may be seen nipped into the folds. These beds contain *Monograptus dubius*, Suess, as the characteristic fossil. *M. dubius* is known in other areas to come in abundantly in the Zone of *Cyrtograptus symmetricus*, immediately above the Zone of *Monograptus riccartonensis*; it is therefore extremely likely that these beds, together with the flags and thin grits overlying them (which have only yielded a graptolite very like *M. basilicus*, Lapw.), represent the horizon of the Zone of *Cyrtograptus symmetricus*.

Beyond the Old Limekiln (where the 'Orange Shales' are not very well seen, but appear to be sharply bent) a series of flags with thin grits comes on, representing the highest Salopian beds of the district. They are exposed in a broad syncline the axis of which lies approximately beneath the Cottage, and are seen once again in a smaller fold near the termination of the section; apparently the intervening portion is chiefly occupied by folds of the Shales containing *Monograptus dubius*. (See section on Pl. VIII.)

VI. Comparison with other Areas.

In its broad outlines the succession of beds at Conway agrees well with that of other British areas. There are, however, two outstanding difficulties :—

(1) Where to draw the line between the Llandeilian and the Caradocian.
(2) Where to draw the line between the Ashgillian and the Valentian.

Difficulties such as these naturally arise when beds pass gradually into each other, as they do in the Conway District; but, in this case, the palæontological evidence seems to demand that the junction between the Llandeilian and the Caradocian should be

drawn near the top of the Cadnant Shales; while that between the Ashgillian and the Valentian may eventually prove to lie in the middle of the Conway Castle Grits. With regard to these last, all that appears certain is that the upper part of them represents part, at any rate, of the Hirnant Limestone, and that this upper part, since it passes laterally into beds with a characteristic assemblage of Lower Llandovery graptolites, must be regarded as being of Lower Llandovery age. Whether or not the lower grits with their associated unfossiliferous shaly beds should also be regarded as representing the Hirnant Limestone; whether they are the equivalents of the Slade Beds of South Wales, or of the *Phyllopora*-Beds of the Lake District; or whether these two also represent part of the Hirnant Limestone, must be left for future work to decide. There appears to be, at present, no definite evidence on this point at Conway.

South Wales.—With regard to the lower beds, the resemblance, as a whole, of those of the Conway District to those of South Wales is distinctly striking. The shales in the Volcanic Series contain the same characteristic graptolite as the Llandeilo Flags, and the Cadnant Shales correspond precisely with the beds termed the Upper *Dicranograptus*-Shales by the officers of the Geological Survey ('Summary of Progress for 1907' 1908, p. 39.)

The greater part of the Bodeidda Mudstones seem to correspond with the Sholeshook Limestone, since they contain *Trinucleus seticornis* down to their very base; and the Deganwy Mudstones are closely comparable with the Redhill Beds.

The upper beds, on the other hand, seem to find their closest parallel in the succession at Rhayader and Tarannon, as described by Dr. H. Lapworth [1] and Mrs. Shakespear.[2]

Rhayader.—At Rhayader, it would seem that the upper part of the Conway Castle Grit is possibly represented by the Cerrig-Gwynion Grit, the flags with *Mesograptus modestus* by the Dyffryn Flags and part of the Ddol Shales, while the shales of the Zone of *Monograptus gregarius* are to be correlated with the upper part of the Ddol Shales and the Gigrin Mudstones. The higher shales with *Monograptus sedgwicki* correspond with the Gafallt Beds, and the rest of the Gyffin Shales are represented by the Rhayader Pale Shales, in part at any rate.

Tarannon.—In the Tarannon country the comparison is even closer, the most noteworthy differences being the absence of a lithological type resembling the Conway Castle Grits at the base, and the fact that at Conway there are no grit-beds corresponding with the massive Talerddig Grits of the Tarannon area, that horizon

[1] Quart. Journ. Geol, Soc. vol. lvi (1900) p. 67.
[2] *Ibid.* vol. lxii (1906) p. 644.

at Conway being represented by unfossiliferous Pale Shales. For the rest, the beds can be correlated almost zone by zone, although in some cases, owing to poverty of exposures, it has not been possible to subdivide the beds with the same degree of accuracy as in the Central Wales district.

Lake District.—The correlation with the Lake-District beds is also fairly clear for the upper beds, and it seems possible that the Conway Mountain Volcanic Series may be comparable with the Borrowdale Volcanic Group. The Cadnant Shales of the Conway area are, however, represented in the Lake District by rocks of a different lithological type, and no close comparison can therefore be made. It would, nevertheless, seem likely that the Bodeidda Mudstones correspond with the *Staurocephalus*-Limestone, since the Deganwy Mudstones are undoubtedly, in the main at any rate, the equivalents of the Ashgill Shales.

The Gyffin Shales may also be regarded as comparable with the Stockdale Shales (Skelgill + Browgill Beds), and the Benarth Flags and Grits are certainly very much like the Brathay Flags, although the Grits are as a rule less conspicuous in the Lake District; the faunas are, however, practically identical.

South Scotland.—The whole succession has also certain points of resemblance with the South of Scotland, though the Caradocian beds of the two areas are represented by different lithological types. Nevertheless, the faunas of the remaining beds appear to correspond so closely that the horizon of these is not left in doubt.

The Cadnant Shales of Conway are clearly represented by the upper part of the Glenkiln Shales of the South of Scotland and the lower zones of the Hartfell Shales. The Deganwy Mudstones, containing *Orthograptus truncatus* var. *abbreviatus*, must correspond generally with the Zone of *Dicellograptus anceps*; and it therefore follows that the Bodeidda Mudstones must be represented by the Zone of *Pleurograptus linearis* and the Barren Mudstones. The correspondence of the higher beds in both areas is also close (see table, facing p. 190).

North Ireland.—In the Pomeroy District (County Tyrone) the succession, so far as it goes, also agrees well with that of the Conway area, though neither the highest nor the lowest beds are represented. The Killey Bridge Beds of Pomeroy have a fauna almost identical with that of the Bodeidda Mudstones, and the Tirnaskea Beds agree closely both in fauna and in lithological characters with the Deganwy Mudstones; there are no grits comparable with the Conway Castle Grits, but the shales and mudstones which overlie the Tirnaskea Beds can be paralleled almost bed for bed in the Conway country.

The resemblances and differences in these various areas are summarized in the accompanying table (facing p. 190).

VII. Petrological Notes on the Lavas.

The Conway Mountain lavas are all classed as rhyolites in the present paper, but they are by no means of uniform type and differ as regards both their macroscopic and their microscopic characters. Taken as a whole, they agree in the general paucity of phenocrysts, which are difficult to detect in hand-specimens; but under the microscope the phenocrysts are more conspicuous, and are usually orthoclase or oligoclase. Ferromagnesian minerals are very rare, although in one rock pseudomorphs after idiomorphic augite have been observed.

With regard to the Nodular Rhyolites, there is nothing to add to the description of these rocks already given by Prof. Bonney, Prof. Cole, and Mr. Harker (*op. cit.*).

As regards the other rhyolites, the differences come out most conspicuously in the characters of the ground-mass: this may be said to be of two types—(1) confusedly microcrystalline, and (2) trachytic.

Broadly speaking, the first is characteristic of the Upper Brecciated Rhyolites, while the second is commonest among the members of the Lower Banded Group. These last certainly are highly felspathic rocks, with a good deal of quartz and little or no ferromagnesian mineral; flow-banding is beautifully shown by the trend of the felspar-microlites. On the grounds of this trachytic structure there may be objections to their inclusion among the rhyolites, but although they were perhaps originally somewhat more basic than the higher lavas of the series, it is scarcely possible, as Mr. Harker has pointed out to me, to term them andesites, when the paucity of ferromagnesian constituent is taken into account.

Micropœcilitic structure is common in rocks of the first type, though it also occurs in patches in rocks of the second type; it is evidently a secondary structure, and would seem to be a frequent accompaniment of the processes of silicification and devitrification. In some cases, the quartz enclosing the felspar forms a more or less regular mosaic resembling that of vein-quartz.

Slide I. Dark-grey banded rhyolite, New Quarry, northern slope of Conway Mountain (western end).—This slide, which is cut at right angles to the direction of flow, shows phenocrysts of orthoclase and oligoclase in a trachytic ground-mass.

The phenocrysts are unusually abundant, and show a tendency to occur in groups; they are all more or less altered, some being sericitized, while others are replaced by calcite or dolomite and another brightly-polarizing mineral (which Mr. Fearnsides considers is an epidote). Flow-banding is indicated by the felspar-microlites; and there is in places a tendency in the direction of micropœcilitic structure, but it is not at all pronounced.

Slide II. Light-grey banded rhyolite, same locality.—This slide is cut parallel to the flow, which is clearly seen. The rock is

G THE CORRELATION I AREAS.

Central Wales (Rh	uth Scotland (Moffat).	Ireland (Pomeroy).
	on Beds. one of *Monograptus riccartonensis.* one of *Cyrtograptus murchisoni.*	
	ds. awick Beds.	
hayader Pale Shales with *Monograptus crisp*	Beds, with *Monograptus griestonensis.* n and Gala Grits, with *Monograptus crispus* and *M. exiguus.*	
with *Monograptus turri*	rd Flags, with *Monograptus turriculatus, M. exiguus,* and *Rastrites maximus.*	
aban Group. 2. Gafallt Beds with *Mon* 1. Caban Conglomerate.	l Shales. one of *Monograptus sedgwicki.* one of *Cephalograptus cometa.*	Limehill Beds.
wastaden Group. 4. Gigrin Mudstones. Z *Monograptu* 3. Ddol Shales { Zone of *Mon* / Zone of *M. c* / Zone of *M. t* 2. Dyffryn Flags.	one of *Monograptus gregarius.* one of *Orthograptus vesiculosus.*	Mullaghnabuoyah Beds. Eden Vale Beds. Slate Quarry Beds.
1. Cerrig-Gwynion Grits	one of *Cephalograptus acuminatus.*	Crocknagargan Beds.
	l Shales. one of *Dicellograptus anceps.*	Tirnaskea Beds.
	Barren Mudstones. Zone of *Pleurograptus linearis.*	Killey Bridge Beds. Bardahessiagh Beds ?
	Zone of *Dicranograptus clingani.* Zone of *Climacograptus wilsoni.*	
	n Shales. e of *Nemagraptus gracilis.*	

TABLE ILLUSTRATING THE CORRELATION OF THE ORDOVICIAN AND SILURIAN ROCKS OF CONWAY WITH THOSE OF OTHER BRITISH AREAS.

Conway District.	South Wales.	Central Wales (Rhayader).	Central Wales (Tarannon).	Lake District.	South Scotland (Moffat).	Ireland (Pomeroy).
SALOPIAN. **Benarth Grits and Flags.**						
3. Zone of *Cyrtograptus symmetricus.*			Fynyddog Grits.	**Brathay Flags.**	**Riccarton Beds.**	
2. Zone of *Monograptus riccartonensis.*			Nant-y-sgollen Shales: 2. Zone of *Monograptus riccartonensis.*		2. Zone of *Monograptus riccartonensis.*	
1. Zone of *Cyrtograptus murchisoni.*			1. Zone of *Cyrtograptus murchisoni.*	Zone of *C*[illegible]	1. Zone of *Cyrtograptus murchisoni.*	
VALENTIAN. **Gyffin Shales.** 6. Zone of *Monograptus crenulatus.*			Dolgau Beds. Zone of *Monograptus crenulatus.*	**Stockdale Shales.** Upper Browgill Beds.	**Gala Beds.** Upper Hawick Beds.	
		Rhayader Pale Shales	Talerddig Grits. Zone of *Monograptus griestonensis.*		Grieston Beds, with *Monograptus griestonensis*	
5. Zone of *Monograptus crispus.*		with *Monograptus crispus*, etc.	Gelli Group. Zone of *Monograptus crispus.*	Lower Browgill Beds. 9. Zone of *Monograptus crispus.*	Buckholm and Gala Grits, with *Monograptus crispus* and *M. exi*[illegible]	
4. Zone of *Rastrites* [illegible] with *Monograptus turriculatus.*		with *M*[illegible] *turriculatus*, etc.	Bryn[illegible] Group. Zone of *Mono*[illegible]*latus* with *Rastrites maximus.*	1. Zone of *Monograptus turriculatus*	Abbotsford Flags with *M*[illegible] *turriculatus, M. ex*[illegible] and *Rastrites maximus.*	
3. Zone of *Monograptus sedgwicki*		Caban Group. 2. Gafallt Beds with *Monograptus sedgwicki.* 1. Caban Conglomerate.	Twymyn Group. Zone of *Monograptus sedgwicki.* Zone of *Cephalograptus cometa.*	**Skelgill Beds.** 7. Zone of *Monograptus sedgwicki.* 6. Zone of *Monograptus clingani.*	**Birkhill Shales.** 5. Zone of *Monogr*[illegible] 4. Zone of *Cephalograptus cometa.*	[illegible] Beds.
2. Zone of *M*[illegible]		Gwastaden Group. 4. Gigrin Mudstones. Zone of *Monograptus convolutus* 3. Ddol Shales: Zone of *Monograptus fimbriatus*; Zone of *M. cyphus.* Zone of *M. tenuis (?)*	Dolgadfan Group. Zone of *Monograptus convolutus.* Zone of *Monograptus fimbriatus.*	5. Zone of *Monograptus convolutus* 4. Zone of *Monograptus argenteus* 3. Zone of *Monograptus fimbriatus.*	3. Z[illegible]	Mullagh[illegible] Beds
1. Zone of *Mesograptus modestus.*		2. Dyffryn Flags.	Zone of *Dimorphograptus swanstoni.* Fachdre Group.	2. Zone of *Dimorphograptus confertus.*	2. Zone of *Orthograptus vesiculosus*	Eden Vale Beds. Slate Quarry Beds
Conway Castle Grits.		1. C[illegible] Grits (?)		1. Zone of *Cephalograptus acuminatus*	1. Z[illegible]	[illegible] Beds
ASHGILLIAN. **Deganwy Mudstones.**	Slade (?) and Redhill Beds.			*Phyllopora*-Beds (?) and Ashgill Shales	**Hartfell Shales.** 5. Z[illegible]	[illegible] Beds
Bodeidda Mudstones.	Sholeshook Limestone.			*Staurocephalus*-Limestone.	4. Barren Mudstones. ?3. Zone of *Pleurograptus linearis.*	Killey Bridge Beds. Bardahessiagh Beds?
CARADOCIAN. **Upper Cadnant Shales.** 4. Zone of *Dicranograptus clingani.* 3. Zone of *Climacograptus wilsoni (?)*	*Dicranograptus*-Shales.			Sleddale and	2. Zone of *Dicranograptus clingani.* 1. Zone of *Climacograptus wilsoni*	
LLANDEILIAN. **Lower Cadnant Shales.** 2. Zone of *Dicranograptus brevicaulis* and *Mesograptus multidens.* 1. Zone of *Climacograptus peltifer.* **Conway Volcanic Series.**	*Dicranograptus*-Shales. Llandeilo Flags.			Roman Fell Group. Borrowdale Volcanic Series.	**Glenkiln Shales.** Zone of *Nemagraptus gracilis.*	

very similar to No. 1; the phenocrysts are fewer in number, one group showing, however, a radial arrangement, and the trachytic character of the ground-mass is more pronounced.

Slide III. Green rhyolite, Railway-bridge.—In this rock the felspar-phenocrysts are larger and more conspicuous than in any other rock of the series; they are mainly orthoclase, some still show Carlsbad twinning, while others are almost entirely replaced by calcite or dolomite. The ground-mass is distinctly micropœcilitic in places, the trachytic character being less pronounced, and the lines of flow are well marked by bands of opaque dust. There is also some ilmenite present, as well as a chloritic mineral of secondary origin.

Slide IV. Dark-grey rhyolite, top of hill above Reservoir.—This rock is the most characteristic of the 'trachytic' types: the felspar-phenocrysts are mainly oligoclase, as are also the microlites of the ground-mass; flow-banding is beautifully shown, and micropœcilitic structure clearly indicated.

All these four rhyolites are members of the Lower Banded Group.

Slide V. Lower Creamy Rhyolite, Road-quarry II.—The phenocrysts in this rock are of oligoclase and pseudomorphs after an augite of somewhat peculiar habit. The ground-mass varies: some bands show minute felspar-microlites, others are micropœcilitic, and there is much to support the hypothesis that the rock was once glassy.

Slide VI. Upper Creamy Rhyolite, western end of Conway Mountain.—There are in this rock a few highly altered phenocrysts of felspar, in a conspicuously micropœcilitic ground-mass.

Slide VII. Upper Creamy Rhyolite, near the 'tear'-fault, eastern end of Conway Mountain.—This slice shows the effect of shearing, sericite being developed along more or less definite planes of foliation.

Slide VIII. Penmaenbach rock, Headland Quarry, Penmaenmawr Road.—This is the rock which occupies the whole of the hill of Penmaenbach. It is a light-grey rhyolitic rock, which is, however, rather more coarsely crystalline than any of the lavas on Conway Mountain, and appears to fill an old neck. Under the microscope it shows some highly altered crystals of felspar and (?) bronzite in a micropœcilitic ground-mass, the felspar-microlites and the enclosing quartz-grains being of larger size than in the common type of rhyolites of Conway Mountain.

A section of this rock taken from the edge of the neck shows that the rock is more conspicuously porphyritic there, and appears to be also richer in quartz.

In conclusion, I wish to acknowledge my indebtedness to my friend Mrs. Shakespear, who has allowed me to make free use of all the notes and observations made by us jointly during the progress of our earlier work. My friend and pupil Miss E. G. Welch has also assisted me, both in the field in mapping the Volcanic Series, and by furnishing me with notes on the lavas from which the description of these rocks was drawn up; to her and to Mr. O. T. Jones, who has helped me in the correlation of the beds, I offer my grateful thanks. I wish also to acknowledge the assistance that I have received from Mr. Alfred Harker, Mr. W. G. Fearnsides, and Mr. R. H. Rastall in the interpretation of the rock-slices, the results of which are embodied in the last section of this paper.

EXPLANATION OF PLATE VIII.

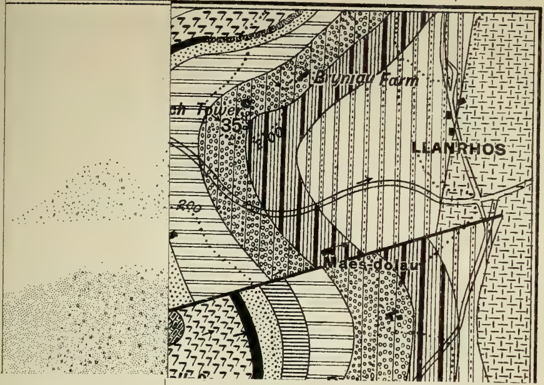
Geological map of the neighbourhood of Conway, on the scale of 3 inches to the mile; and section on the west side of the River Conway, on the scale of approximately 6 inches to the mile.

Discussion.

Mr. H. H. Thomas congratulated the Author on the excellent way in which she had disentangled the structure of a complicated district, and once again presented to the Society a detailed account of a most important geological succession: work made possible and doubly valuable by her knowledge of palæontology. It was most satisfactory also when the age of a volcanic series could be so accurately defined as it had been in the present instance.

With regard to the *Dicranograptus*-Shales, he remarked on the advantage that he had received from the Author visiting with him some of the chief sections in South Wales. He commented on the remarkable lithological resemblance offered by the shales at Conway to those in Caermarthenshire, where the same lithological changes occur with the same faunal difference. While agreeing perfectly with the Author as regarded the line which should be taken as dividing Glenkiln from Lower Hartfell, he felt that this line could not logically represent the division between Llandeilo and Bala. At Llandeilo the Llandeilo Flags were the only rocks that could be included in Murchison's Llandeilo Formation, the *Dicranograptus*-Shales which occurred above belonging naturally to the Bala. The shales above the Llandeilo Flags at Llandeilo contained exactly the same fauna as the shales described by the Author as occurring above the Conway Volcanic Series. The speaker recognized that there were difficulties in the way, but suggested that the dividing-line between Llandeilo and Bala should, in the Conway district, be drawn at a lower horizon than that indicated in the paper.

Mr. W. Whitaker asked whether the correlation of the Conway Grits with the Hirnant Limestone depended only on palæontological evidence, or whether continuity of the beds had been traced.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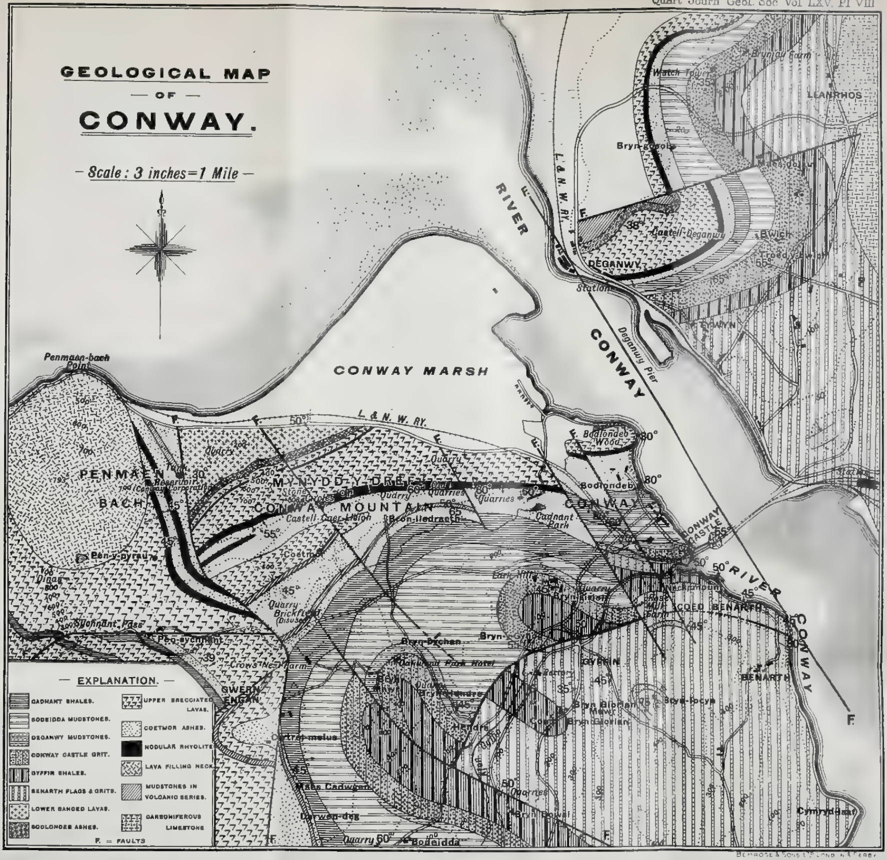
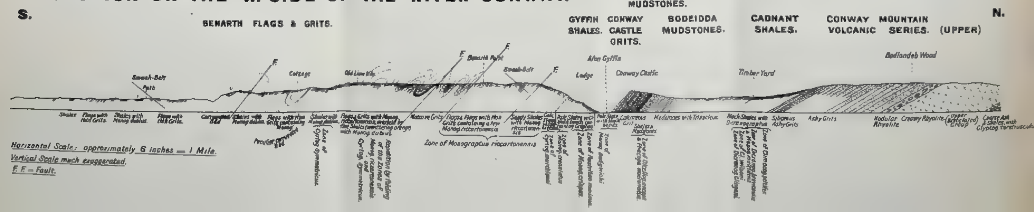


SECTION ON THE W. SIDE OF THE RIVER CONWAY.



Mr. J. Hopkinson said that he had been greatly interested in the paper, as he had many years ago collected graptolites from the black shales in the area described by the Author, then concluding from their evidence alone that the lower beds were of Llandeilo age. This the Author had now proved from the general succession of the strata which she had so well worked out and so lucidly brought before them, as well as from her intimate knowledge of the graptolites by which she had been enabled to make out in detail the succession of the fossiliferous strata. The Society was much indebted to her, for bringing before it the results of her investigations in a district of great geological interest.

Prof. W. W. Watts congratulated the Author on having found a section in Wales which bridged over the gap between the Ordovician and the Silurian rocks, thus showing the palæontological character of beds very little known elsewhere. The Author had also contributed a very important piece of evidence with regard to the position of the volcanic members of the series in Wales. In this connexion, he recalled Mr. Harker's placing of the Conway volcanic rocks very low down in the Snowdonian Series. He referred to the Hartfell-Glenkiln fauna, which, divided into two distinct horizons in Scotland, presented a union at many localities in Wales and the Borders.

Mr. E. A. Martin congratulated the Society on the excellent paper which a lady-geologist had placed before them.

The President (Prof. Sollas) remarked on the great interest of this paper, especially in its relations to general questions. The concordant sequence of the strata of the two systems described should not, he thought, be identified with conformity. The great break at the base of the Silurian, which was so marked a feature in South Wales, and in many parts of the world more remote, was probably not so much absent at Conway as not apparent. The inconsiderable thickness of the two series, as measured by the Author, by itself suggested a lapse of stratigraphically unrecorded time. These deceptive conformities presented a problem of great interest, which still awaited solution.

The Author in reply thanked the President and Fellows of the Society for their generous appreciation of her work. With regard to the points raised by Prof. Watts and Mr. Thomas as to the age of the different members of the *Dicranograptus*-Shales, the beds were considered to be Lower Hartfell where the large Diplograpti (Orthograpti) came in, in great numbers; and this was a very easy horizon to recognize in the field, without any special knowledge of graptolites. Below these were beds constituting a passage-zone, characterized by *Dicranograptus brevicaulis* and *Mesograptus multidens*; in the lower parts of the zone, the fauna showed decided Glenkiln affinities, while in the higher there was indication of the incoming of the lower Hartfell fauna. The beds below this zone contained a decided Glenkiln fauna, and she was of the opinion that there were serious palæontological objections to their inclusion

in the Bala as Mr. Thomas had suggested. It might be possible to recognize the horizon where a limestone (such as the Mydrim Limestone) immediately underlay the shales; but, where the calcareous facies did not occur, she thought that it would be found that a similar fauna would extend down into much lower beds.

With regard to the point raised by Mr. Whitaker, the Author stated that she had traced the Calcareous Grits for a considerable distance in a southerly direction; and, although she had not mapped the Hirnant area, she had every reason to believe that the beds overlying the limestone were the same as those in the Conway District.

11. PLANT-CONTAINING NODULES *from* JAPAN, CONSIDERED STRUCTURALLY *in their* RELATION *to the* 'COAL-BALLS' *and* 'ROOF-NODULES' *of the* EUROPEAN CARBONIFEROUS.

By MARIE C. STOPES, D.Sc., Ph.D., F.L.S. (Communicated by Prof. E. J. GARWOOD, M.A., Sec.G.S. Read February 24th, 1909.)

[PLATE IX.]

CONTENTS.

I. INTRODUCTION.

THE nodules of which the geological nature is described in this paper are of interest and importance, chiefly because of the plant and animal fossils which they include. The plant-petrifactions are of a type unknown from the Mesozoic; these I am describing in a botanical paper in conjunction with Prof. Fujii, of which we hope the first part will be ready for publication in a few months.

A critical study of the structure and mode of formation of the plant-containing nodules, though a special branch of geological work, is of some value to the students of plants, and in the case of the Carboniferous nodules seemed to repay fully the labour which it entailed. Hence the present short comparative study of the Cretaceous nodules was undertaken.

Recent work[1] on the structure of the Carboniferous nodules brought out decisively what had been spoken of in a general way, namely, the importance of the association of marine organisms with the coals and associated rocks in which they were formed. It also showed that it is when saturated with sea-water that plants seem to stand the best chance of petrifaction, and that only under marine conditions do 'coal-balls' occur in the coals. As it is in

[1] M. C. Stopes & D. M. S. Watson, 'On the Present Distribution & Origin of the Calcareous Concretions in Coal-Seams, known as "Coal-Balls"' Phil. Trans. Roy. Soc. ser. B, vol. cc (1908) pp. 167–218, pls. xvii–xix.

the coal-balls that such storehouses of tissue-petrifactions are to be found, they are of particular importance to the plant-anatomist. This led me to search for marine coals of ages other than Carboniferous, in the course of which a valuable suggestion, followed by specimens, was made by Prof. Fujii, of Tokio. His information appeared to be confirmed by the publication of the Imperial Geological Survey of Japan, wherein it was stated [1] (p. 104):

'But at Yūbari and other coal-mines the distinction between the Tertiary and Cretaceous formations seems not very clear, coal-seams being also found associated with *Ammonites* beds.'

As a result of these clues, in particular the two specimens sent by Prof. Fujii, which much resembled 'roof-nodules,' I set out in search of Mesozoic 'coal-balls' in Japan, aided by a grant from the Royal Society. No coal-balls were found, but the nodules here described contain plant-tissues as well preserved as in the true coal-balls. They are thus of almost equal value to the plant-anatomist, and may prove of considerable botanical importance when fully studied, as no such material is known of Mesozoic age from any other horizon. The following account of the geological nature and structure of these nodules may, therefore, be of interest.

The work on the subject of coal-balls which has been already mentioned (Stopes & Watson, *op. cit.*) gives a comparatively complete account of their structure and mode of formation. The facts presented in that paper must be assumed to be already in the possession of the reader of this, for it is not possible to recapitulate here all the results of the previous work which form the foundation of the standpoint from which the present subject has been considered.

II. Field-Observations.

The Cretaceous rocks which yielded the plant-containing nodules form thick beds in the Northern Island of Japan, Hokkaido. The age and general distribution of these beds has been practically settled by Dr. Yabe's [2] work on the ammonites contained in them. As the plant-containing nodules which we are considering include one or more species of ammonites in nearly every case, his results as regards age apply equally to the plants, which are therefore undoubtedly Upper Cretaceous.

Yabe's paper is concerned only with a detailed description of the ammonites, but in his introductory remarks (p. 5) he gives a short account of the entire Cretaceous series of Hokkaido. I may here

[1] 'Outlines of the Geology of Japan, to accompany the Geological Map of the Empire.' Compiled by the officials of the Imperial Geological Survey of Japan, Tokio (1902) pp. 1-251.

[2] H. Yabe, 'Cretaceous Cephalopoda from the Hokkaidō' parts i & ii, Journ. Coll. Sci. Imp. Univ. Tokio, vols. xviii & xix (1903 & 1904).

state that Dr. Yabe's kindness in lending to me his field-maps made the present work less arduous than otherwise would have been the case. According to Yabe, the Cretaceous is purely marine, and the beds lie ('after Jimbō and the general usage of Japanese geologists') immediately above the Palæozoic, while they gradually merge into the Tertiary above, from which it is difficult to separate them. Yabe divides the Cretaceous into three main divisions:—I, the Lower Ammonite-Beds; II, the *Trigonia*-Sandstone Series; and III, the Upper Ammonite-Beds. It is in the last-named that the nodules which we are now considering are found.

At first I hoped to find coals interbedded with marine rocks in which were true 'coal-balls,' and for this purpose a number of coal-mines in the district were carefully examined. There was, however, no trace of any true nodule or coal-ball in the coals, although large silicified masses occurred in some seams in great numbers, which are apparently identical with those in the Tertiary coals of Kyūshū in Southern Japan. These consist almost entirely of silicates and carbon, and contain no delicate tissue-petrifactions, as they enclose only the wood of big trunks. As their nature and origin appear to be fundamentally different from those of coal-balls, they will be considered in a separate paper. The examination of the mines left me in grave doubt as to whether any of the coals above the Cretaceous were truly marine, for in those cases in which Cretaceous fossils were reported to have been found in the mines, the most careful examination and the closest questioning of the local authorities and workmen could bring to light no suggestion of their existence within a hundred feet of the coal itself. Hence it was concluded that the plant-nodules could not correspond either to the 'coal-balls' (from the seam itself) or to the 'roof-nodules' (from the roof-rocks immediately above the coal), which are the sources of petrified plants in the Coal-Measure Series of England. The Japanese coals are presumably freshwater deposits, and lie some distance above the shales in which the nodules are found.

Before proceeding, it is necessary to say a few words about the nature of the ground which the geologist must traverse in these regions, as it largely accounts for the relative uncertainty that exists about points which could be fully known in an inhabited part of the country. In the immediate neighbourhood of the coal-mines themselves are clearings, roads, and even railways for the transport of the coal, but a few yards from the mining settlement one enters virgin, trackless forest. Here the trees grow thickly, and the ground is entirely covered with a tangle of a genus of bamboo-grass 6 feet high, and a variety of prickly shrubs beneath the trees. To force a path through this is a great labour, and is entirely profitless, for the geology of the ground is completely hidden by the rank vegetation. Hence, beyond the mines, where there are no footpaths, the only place to find exposures and the only possible track to follow is the bed of a river. The

rivers are too strong and rapid to allow of boating, and the sides are often too steep to permit of one's walking along them; but by frequent crossings through the water it is possible to navigate them on foot. This physical difficulty, and the trouble and expense of carrying specimens and tents by coolies, as also the relatively small amount of exposure which the geologist has to work upon, account for several of the uncertainties that exist about these beds.

Among the large waterworn pebbles numerous specimens of plant- and ammonite-containing nodules are to be found, many of which have proved to contain well-petrified plant-fragments. Of the many nodules which lie washed out in the course of the stream, the plant-containing nodules of the Upper Cretaceous beds are recognizable by the ammonites enclosed in them, as well as by the special creamy-yellow colour which they have when weathered. They vary much in size, some being an inch or two in diameter, others a foot or more. The very largest that I observed was 5 feet in diameter, but it was partly broken, and as its shape was that of an almost perfect oblate spheroid, it must have measured 6 feet when complete. Up to 2 feet in diameter was no uncommon size, but those measuring over 2 feet were very few. In several of the large concretions lying *in situ*, both plants and ammonites were seen embedded.

The identity in age of the fossils in the nodules and of the shales enclosing them could not be assumed; but, although the plant-fragments were not well enough preserved to be recognizable, animal fossils were found in the shales of the same species as those in the nodules. Hence the fossils in the nodules, both plant and animal, can be fairly considered as representing the life of the period in the locality of these deposits.

In some of the nodules, when broken open, could be seen small fossils embedded in distinct layers, showing that the concretions had formed round the organic remains as they lay stratified in the shale, just as was found to be the case in the 'roof-nodules' from the Coal-Measures (see Stopes & Watson, *op. cit.* p. 180).

Not far from the very large nodules lying *in situ* I observed thicker, sandier slabs than usual in the shale, on which were numerous worm-tracks and sun-cracks, which seemed to afford good evidence that the nodules had been formed at no great distance from a shore. The shales were practically free from any of the elements of a breccia or conglomerate, so that the coast was presumably neither a rocky nor a pebbly one, but rather protected, with fine sandy and muddy deposition.

III. Microscopic Structure of the Nodules.

It is characteristic of the true 'coal-ball' that the mineral matrix is homogeneous, and there are no intrusive grains of quartz, or even of mud. They are approximately pure carbonate-concretions formed in a mass of plant-tissue. The 'roof-nodules,' on the other hand,

show an opaque matrix, formed of the very fine-grained silt that was accumulating to form the roof and was included in the concretions growing round the plant-fragments as centres. This distinction is borne out by the chemical analyses of these two types of plant-containing nodules (see Stopes & Watson, *op. cit.* pp. 193 & 196, for full details, and this paper, p. 200, for single analyses), as well as the physical conditions under which they appear to have been formed. Knowing, then, that the plant-containing nodules of Hokkaido were formed much farther from the protected quiet of a coal-deposit, and that in fact they were almost at the shore in some cases at any rate, it is not surprising to find that they are very much more granular than the Palæozoic 'roof-nodules.'

A photograph of a portion of the matrix of a Japanese nodule is shown in Pl. IX, fig. 1, where the numerous and irregular grains in the matrix can be seen all through it. Many of these grains are quartz-crystals—things practically unknown in the 'roof-nodules.' Among the granules in some specimens are compound silicates, some of which are brilliantly coloured red or green under normal light. There are also calcite-crystals, some of large size, and a number of opaque granules. The number and size of these granules and crystals vary considerably in the different nodules; some being coarse throughout, some exhibiting coarse-grained bands or layers, and some being almost as fine-grained as the Palæozoic roof-nodules.

In most of the nodules also are shells, some of minute size, others merely portions of various large mollusca and ammonites. The number of the shells in a nodule is also very various, but some are to be found in nearly every case. These are often mixed with fragments of plant-tissue, as is seen in Pl. IX, fig. 2, *s*.

Plant-fragments are found with well-preserved tissues in many of the nodules, both in those of very large and in those of average size. In a number of cases the fragments are isolated, a single stem or twig in a single nodule, as is the case in the typical Carboniferous 'roof-nodule.' But in most cases two or more fragments lie together, and in a few of the nodules the plant-tissues lie so thickly massed, and contain portions of such a variety of organs that the nodule may be said to approximate very closely to a true 'coal-ball.' Such a case is illustrated in Pl. IX, fig. 3, which presents the same appearance as a 'coal-ball' with its crowded mass of débris.

In most cases, however, even where there are numerous fragments from several plants in the same nodule, there is a quantity of matrix round and between them, a point in which these nodules differ from 'coal-balls.'

In the co-existence of plant and animal remains in the same nodule, the Japanese nodules agree with the 'roof-nodules' of the European Carboniferous Period; while in the presence of numerous small fragments of plant-débris of many kinds in the same nodule they agree with the 'coal-balls.'

In the delicacy of the preservation of the enclosed tissues also, particularly in the good petrifaction of leaves, twigs, spores, and such small fragmentary structures, the type of petrifaction approximates more closely to that of the roof-nodules. Pl. IX, fig. 4 shows a transverse section of a stem, and in fig. 3 at *b* can be seen a fragment of a leaf and other tissue which suffice to show the quality of the preservation which the Japanese nodules may yield. Though portions equally well, or better, preserved could be brought for comparison from the 'roof-nodules' of the Carboniferous, yet the impression derived, after going carefully through hundreds of slides, is that the Japanese nodules show better-preserved small fragments than do the 'roof-nodules.' Moreover, the former give the impression that they had not been subjected to the vicissitudes which had so often damaged the plants in the 'roof-nodules' before they had been petrified—in fact, judging from the character of the plant-remains alone, the Japanese nodules approximate more nearly to the 'coal-balls' than to the 'roof-nodules' in their petrifaction.

IV. Chemical Analysis of the Nodules.

The importance of detailed chemical analyses as a foundation for the critical consideration of plant-containing nodules was brought out in the work on the Carboniferous structures, so that, for comparison with them, the analyses of the nodules here described are essential. Owing to the kindness of Prof. Sakurai, of the Imperial University, Tokio, Mr. Kurihara was persuaded to carry out two analyses of Yubari nodules, while Mr. J. Barnes, of Salford, who carried out those for the previous work, analysed two further samples.

Analyses by Mr. Kurihara. Japanese Nodules.

	I.		II.	
Calcium carbonate, $CaCO_3$	64·29	65·34	46·07	54·13
Magnesium carbonate, $MgCO_3$	1·05		8·06	
Iron carbonate, $FeCO_3$	10·50		8·88	
Silica, SiO_2	23·04		30·46	
Water, H_2O	0·37		...	
Carbon, C	...		2·07	
Other substances	0·75		4·46	
Totals	100·00		100·00	

In these two cases, when the calcium and magnesium carbonates are added together and treated as one,[1] there is seen to be no

[1] This is entirely justifiable, for in a series of nodules from the Carboniferous it was found that calcium and magnesium are interchangeable—the relative proportion of the two elements being widely different, though the total of the two carbonates was roughly constant.

fundamental difference in the specimens, though the first has a rather larger proportion of carbonates and the second a larger proportion of silica.

The nodules consist primarily of calcium carbonate and silica, as would be expected from the nature of the crystals in the coarse matrix.

The following analyses are carried out in rather more detail, but show a similarity to the foregoing in the main feature, namely, that the nodules consist primarily of carbonates and silicates. The presence of aluminium is to be noted (aluminium silicate was probably classed as silica by the first analyst) in these nodules, as its practical absence from the 'coal-balls' is a striking feature of their composition.

ANALYSES BY MR. BARNES. JAPANESE NODULES.

	Typical nodule.		*Many fragments from a number of nodules, to give a fair sample of the whole.*	
Calcium carbonate, $CaCO_3$	59·391	60·409	58·256	59·180
Magnesium carbonate, $MgCO_3$	1·018		0·924	
Iron carbonate, $FeCO_3$	1·739		2·156	
Insoluble inorganic substances, mainly aluminium silicate	32·256		30·744	
Manganese carbonate, $MnCO_3$	0·896		2·279	
Calcium phosphate, $Ca_3P_2O_8$	0·811		1·600	
Iron pyrites, FeS_2	0·743		0·483	
Carbon (organic), C	1·545		0·993	
Aluminium hydrate, $Al_2H_6O_3$	1·497		2·522	
Totals	99·896		99·957	

For the sake of comparison, analyses are tabulated of a 'coal-ball' and of a 'roof-nodule':—

ANALYSES BY MR. BARNES. (From Stopes & Watson, *op. cit.* pp. 193 & 197.)

	'Coal-ball.'		*'Roof-nodule.'*	
Calcium carbonate, $CaCO_3$	52·378	92·262	84·700	86·300
Magnesium carbonate, $MgCO_3$	39·884		1·600	
Iron carbonate, $FeCO_3$	2·973		2·448	
Aluminium silicate (clay)	0·000		6·447	
Manganese carbonate, $MnCO_3$	1·167		1·808	
Calcium phosphate, $Ca_3P_2O_8$	trace		trace	
Iron pyrites, FeS_2	0·783		1·280	
Iron oxide, Fe_2O_3	0·113		...	
Carbon (organic), C	2·281		1·473	
Aluminium oxide, Al_2O_3	trace		0·216	
Water, H_2O	0·283		0·000	
Totals	99·862		99·972	

Though ‘coal-balls’ and ‘roof-nodules’ may vary considerably in detail, these two analyses are representative of their average structure, and show that they consist almost entirely of carbonates. The ‘coal-balls’ are quite free from both silica and clay, while in the ‘roof-nodules’ the percentage of these substances is very small. In other respects, the Japanese and the Carboniferous nodules agree in a general way in their chemical composition. The calcium and magnesium carbonates, together with aluminium silicate, form 92·665 and 89·924 per cent. in the Japanese nodules, and 92·262 and 92·747 per cent. in the Carboniferous nodules.

Tabular Summary of the Principal Features of the Three Types of Nodules (see p. 203).

‘Coal-balls.’	*Japanese nodules.*	*‘Roof-nodules.’*
No animal shells in the matrix.	Many marine shells in the matrix, largely ammonites.	Many marine shells in the matrix, largely goniatites.
Matrix entirely free from granules, with few crystals of calcium carbonate and no quartz.	Matrix extremely granular in most cases. Numerous calcite-crystals and many quartz-grains.	Matrix opaque, but very fine-grained. Very few crystals and almost no quartz-grains.
Numerous closely-packed plant-fragments of many kinds.	Some fragments singly in nodules, others many together in a nodule, but always with much matrix surrounding each.	Fragments almost without exception singly in nodules, consequently surrounded by much matrix.
Chemical composition: about 92 per cent. carbonates and 0 per cent. silicates.	Chemical composition: about 60 per cent. carbonates and 30 per cent. silicates.	Chemical composition: about 86 per cent. carbonates and 6 per cent. silicates.
Rather irregularly-rounded masses, some approaching oblate spheroids.	Some more or less true oblate spheroids in shape, others more irregularly rounded.	Approximately oblate spheroids.
From a few millimetres to 2 feet in diameter, irregular masses much larger.	From 2 inches to 6 feet in diameter.	From 2 inches to about 2 feet in diameter.
All concretions enclosing plant-fragments.	Many concretions enclosing plant-fragments, though similar ones contain only shells.	Many concretions enclosing plant-fragments, though similar ones contain only shells.
Formed in the surrounding layers (coal) saturated with sea-water.	Formed in the surrounding layers (shale) under sea-water.	Formed in the surrounding layers (shale) under sea-water.

V. Comparison and Contrast with Carboniferous Nodules.

The Japanese nodules are found in rocks a considerable vertical distance (usually much more than 100 feet) below the coal-seams in their neighbourhood,[1] while the 'coal-balls' are found in the coal itself and the 'roof-nodules' in the rocks of the roof immediately above the coal, so close as to be sometimes in actual contact with it. Hence, in their geological position, the Japanese nodules differ both from the 'coal-balls' and from the 'roof-nodules.' The difference from the latter, however, is more apparent than real, as will be shown later.

Instead of describing the contrasts in the main features of each of these three types of nodules, a tabulated summary of the principal points is given (p. 202), as the likeness or difference in each case will be more apparent in this form of presentation than in the other.

VI. Conclusion.

That the Japanese nodules are not coal-balls is, of course, immediately apparent, but that they partake of the nature of coal-balls in having numerous fragments of plant-débris preserved in a mass together, as do the coal-balls, is a point of considerable interest. It is this characteristic which will prove their most valuable one to botanists, for in this they excel all the other plant-petrifactions of Mesozoic age which have hitherto been obtained. It is in this feature, too, that they differ from the Carboniferous 'roof-nodules' with which they are so closely comparable in other respects. It has been shown (Stopes & Watson, *op. cit.* p. 204) that the plants in the roof-nodules were presumably waterlogged fragments which had drifted for some time and had been separated from the other débris, the smaller and more delicate of which were scattered (and possibly devoured) and escaped petrifaction. The numerous minute fragments of the Japanese nodules (in which are small rootlets, leaf-scraps, twigs, and spores) could neither have drifted far nor long before they were covered and preserved in that potent preservative and petrifying solution, sea-water.

The presence of ripple-marks and worm-tracks interbedded with the layers, in which also the nodules occurred (see p. 198), is in entire accord with this view, as it proves that the deposits were laid down at no great distance from the shore. Further, the microscopic structure of the nodules, with their numerous quartz-grains and crystals, as well as the chemical composition showing 30 per cent.

[1] In one sense they might be considered as lying above some small coals in the second of Dr. Yabe's divisions, namely, the *Trigonia*-Sandstones. I spent much time in searching for coals in the Mesozoic rocks in actual conjunction with marine fossils, but found only a few thin coals in the stream Bannosawa, which were clearly in the *Trigonia*-Sandstone Series. But, as Yabe says (*op. cit.* p. 6), the *Trigonia*-Series is a more littoral deposit than the Ammonite-Beds; and as there were no fossils immediately above these coals, proof is still lacking that these coals were actually marine.

of silicates of aluminium (clay), indicates clearly that the nodules were formed in a region where detrital matter, from the neighbouring rivers presumably, was being quietly deposited. The whole area in this period was one of deposition; the land was being built up, and, not very much later, thick coals were deposited under what seem to have been freshwater conditions. In the succeeding beds no plant-tissues are petrified in concretionary nodules, nor are there true coal-balls in the coal, as previous work led me to expect from the apparent absence of marine conditions during its deposition.

The fragments, brought down to the sea had the favourable chance of petrifaction, without having drifted far enough to have been scattered or destroyed; then, as the land rose and the sea-water was shut out, the succeeding débris formed coal, but no tissue-petrifactions.

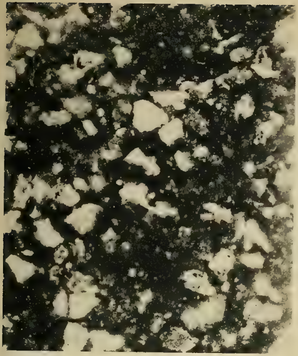
It may be remembered that from the Carboniferous a single 'floor-nodule' was described from below the coal (Stopes & Watson, *op. cit.* p. 180). This resembled the other nodules in the preservation of plant-tissues, but had a larger proportion of clay among its constituents: hence, it is possible that someone might suppose this nodule to be homologous with the Japanese nodules. However, this is not the case, for the 'floor-nodule' had formed by segregation round the roots of the plants growing *in situ*, as was shown by the nature of the petrifactions which it enclosed. The Japanese nodules were formed round drifted fragments, which collected near the shore some time before the deposition of the coals began.

In a few words, one might conclude the matter by saying:—Just as the 'roof-nodules' contain plants which drifted out to sea from a region where coal-deposition had been previously going on, and, sinking, were petrified together with the shells of marine organisms in nodules of concretionary nature; so the Japanese nodules contain plants which drifted but a short distance out to sea from a region where coal-deposition would begin shortly after, and, sinking, were petrified together with the shells of marine organisms in nodules of concretionary nature.

In neither case, probably, do the plants in these marine nodules represent quite the same ecological community as that which later, or earlier, formed the coals. It has been proved that the Carboniferous nodules represent a flora of a somewhat different nature from that in the coal, and so too in all probability the Japanese nodules do not contain entirely the same plants as those which later formed the coal.

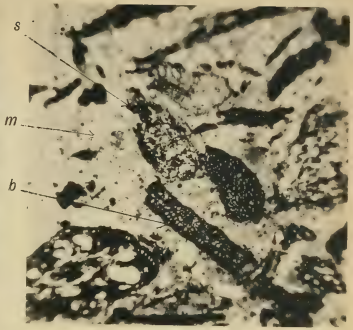
It is, in truth, more or less of an accident that there should be coal-seams associated, either with the 'roof-nodules' from the Carboniferous, or with the Cretaceous nodules. A chance that probably depended, however, on some local facility of transport and deposition which favoured coal-formation; and the currents, before or after they brought masses of plant-tissue sufficient to form coal, continued to carry scattered fragments, which were preserved and petrified with the shell-débris among which they accumulated.

FIG. 1



X 30

FIG. 3



X 20

FIG. 2

X 1

FIG. 4

X 20

M. C. Stopes, Photo.

Bemrose, Collo., Derby.

PLANT-CONTAINING NODULES FROM JAPAN.

VII. Summary.

The nodules are of Upper Cretaceous age.

They are concretions enclosing numerous marine shells and various plant-fragments well petrified.

They are not directly connected with any coal-seam, but lie in a thick series of shales below the coals.

In microscopic section the matrix appears highly granular, unlike the matrix of coal-balls and roof-nodules.

Chemical composition includes roughly 60 per cent. of carbonates and 30 per cent. of silicates, the large proportion of the latter being an important point of difference from the Carboniferous nodules.

In having numerous plant-fragments in a single nodule, and in the type of petrifaction, the nodules are like 'coal-balls'; in having marine shells included in the matrix, they are like 'roof-nodules.'

They probably represent fragments of tangled débris which had drifted but a short distance out to sea, and were then speedily petrified.

This work was done while travelling in Japan with a grant from the Government Grant Committee of the Royal Society. Very material assistance was also rendered by the Imperial Japanese Government through its Geological Survey, the Imperial University, and the local Government of Hokkaido, as well as by the Tanko Kaisha (Coal-Mine Company) of Hokkaido, without whose hearty co-operation the work would have been hardly possible. To everyone who has thus rendered valuable help, I here tender my sincere thanks.

EXPLANATION OF PLATE IX.

Fig. 1. Microphotograph of a portion of the matrix of a plant-containing nodule, showing its highly granular nature. Magnified 30 diameters.

2. Photograph of section through a nodule, showing *s* various scraps of shells, *a* an ammonite in transverse section, *p* plant-fragments, and *st* transverse section of a plant-stem. Natural size.

3. Microphotograph of part of a section through a plant-containing nodule, showing numerous small fragments close together: b = fragment of leaf; m=crystals of matrix; s=clump of plant-sclerenchyma. Magnified 20 diameters.

4. Microphotograph of a transverse section of a stem preserved in a nodule similar to that shown in fig. 3. Magnified 20 diameters.

Discussion.

Prof. Garwood congratulated the Authoress on her interesting discoveries in Japan, and regretted the lateness of the hour which prevented the paper from being read in full; he felt sure that, when the paper was published, it would prove to be an important contribution to the study of those interesting structures, 'coal-balls' and 'roof-nodules.'

12. *Some* Recent Observations *on the* Brighton Cliff-Formation. By Edward Alfred Martin, F.G.S. (Read February 10th, 1909.)

[Abstract.]

The Author records in his paper certain features presented by the face of the cliffs between successive falls at Black Rock, Brighton, during the past eighteen years. As the cliffs have worn back, the base-platform of Chalk grows in height, and the layer of sand which Prestwich found above the Chalk grew thinner and thinner until finally it completely disappeared. At the same time, the raised beach has grown in thickness from $1\frac{1}{2}$ to 12 feet. In 1890 there were 6 feet of sand, with a foot and a half of beach above it. There was practically no protection at this date in the shape of groynes. In 1892 the sand had decreased to between 3 and 4 feet, but the beach remained as in 1890. Many falls of cliff took place between 1892 and 1895, and at the latter date the beach had increased to between 4 and 5 feet. The eastern limit of the beds had become more clearly defined, the trough in the Chalk in which they had been defined taking an upward direction about 300 yards east of the Abergavenny Inn. Many blocks of red sandstone had become dislodged, and were lying on the modern beach. In 1897, 10 feet of chalk formed the lower portion of the cliff, with 8 feet of raised beach above it in places, but there was a mere trace of sand left. The rubble-drift above was seen to be distinctly stratified. Many masses of red sandstone had fallen out of the cliff, the largest measuring 5 feet in its greatest dimension. In 1899, the raised beach had reached a thickness of 10 feet. Great masses of moved and reconstructed chalk were observed on the eastern boundary embedded in the beach. Two rounded lumps of granite were extracted from the beach. In 1903, the beach was but a little over 8 feet thick in the exposed parts, but the platform of Chalk was 14 feet thick. The upper portions of the beach, which were the least consolidated, had fallen away in such a manner as to leave cave-like gaps beneath the rubble. The number of red sandstone blocks which lay on the modern beach was remarkable, forty such blocks being counted in a space of 50 yards square. In 1906, the raised beach had increased from 15 to 20 feet: farther west, however, the thickness was not so great. In 1908, there were 17 feet of Chalk, 12 feet of beach. It is noteworthy that, as the degradation of the cliff proceeds, the material is rapidly carried away by the sea. No talus remains for any length of time, and if the material is to be prevented from disappearing into deep water, some such contrivance as chain-cable groynes seems to be demanded, fixed somewhere between low and high tide-marks. The only organic remains observed in the cliffs were some fragments of shells, found at the top of the raised beach.

Discussion.

The President (Prof. Sollas) remarked that many years ago Mr. Jesson, F.G.S., had found plant-remains in the Elephant Bed at the base of the cliffs east of Brighton. These had been shown to Prestwich and Carruthers, but, owing to their imperfection, had not been determined. Perhaps the Author would state whether he had met with any specimens of better preserved plants.

The Author replied in the negative, and at the same time expressed his thanks for the reception accorded to his paper.

13. *On the* Sculptures *of the* Chalk Downs *in* Kent, Surrey, *and* Sussex. By George Clinch, F.G.S., F.S.A. Scot. *(Read April 7th, 1909.)*

[Abstract.]

The Author classifies the various forms of sculpture of the Chalk Downs under three heads, namely, (1) dry valleys of simple form, (2) dry valleys of complex form, and (3) wet valleys. He draws attention to the relatively small catchment-areas of the dry valleys, and to the large number of tributary valleys found in some districts, two points which he considers have not hitherto received entirely satisfactory explanation.

While accepting the view that frozen conditions in former times altered the drainage-system of the Chalk, he argues that the most potent excavating force was the frost itself, acting on Chalk saturated or highly charged with water. He points out the following peculiarities of dry Chalk valleys :—(1) the great size and breadth of the valleys in relation to their catchment-basins ; (2) the ramifications of some of the valley-systems ; and (3) the termination of many dry valleys just short of the crest of the Chalk Downs.

In order to account for these phenomena, the Author propounds the following theories :—

(1) The chief part of the valley, during and after periods of low temperature, being occupied by a mass of ice, erosion of the Chalk would naturally be more active at the sides than in the bottom of the valley : lateral development and sometimes elaborate ramification being the result.

(2) The diminution of the catchment-area, due to the cutting-back of the valley towards the highest level, would have the effect of removing one of the chief agents in the breaking-up of the Chalk, with the result that the valley would die out just short of the crest of the Chalk Downs.

Discussion.

Mr. E. A. Martin wished to point out that the dry valleys of the Southern Downs, ending quite close to the edge of the escarpment, are merely instances of arrested development. When the lowering of the Wealden watershed took place, some of the southward-flowing streams ceased to flow. Of those that remained, what are now the Adur, Arun, etc. have persisted until modern times ; others were cut off when their work was but half done, hence the gaps at Findon, north of Worthing, and Clayton, north of Brighton, or, in the North Downs, at Merstham. There is thus a regular sequence from the high and dry valleys, and the deeply-cut river-bearing valleys of the present day. The streams which prevailed over those that ceased,

certainly succeeded in overcoming the natural porosity of the Chalk. This, the speaker contended, was in consequence of another characteristic of the Chalk when ground down to powder by running water, namely its ability to make itself a puddled, water-bearing bed. Many of the Downland dew-ponds are held up by a chalk-puddled bottom, seemingly contradictory though it may be to the well-known porosity of chalk in the field.

Mr. G. W. Young thought that the Author had given scant attention to the more recent literature on the subject. The matter had been fully discussed by Mr. Jukes-Browne in the Geological Survey Memoir ('Cretaceous Rocks of Britain,' vol. iii). Had the Author consulted that, he would scarcely have ignored what the speaker regarded as an important factor in the production of these dry chalk-valleys, namely, the solution of the chalk by rain along lines of weakness (joints) especially where unprotected by a clay-covering.

The Author, in thanking the Fellows of the Society for their kind reception of his paper, regretted that he was unable, owing to the lateness of the hour, to reply fully to all the points which had been raised in the discussion.

Replying to the remarks of Mr. E. A. Martin and Mr. G. W. Young, the Author said that he was unable to find sufficient evidence for the origin and development of the dry valleys in the simple forces of atmospheric solution, even when the clay-capping of the Chalk had been removed locally by former streams or rivers. These explanations, although applicable in a restricted degree and in reference to some of the simple valleys, did not, he submitted, adequately account for the development of the sinuous ramifications of complex valley-systems, and were equally insufficient to explain the absence of chalk-débris in many of the coombes.

14. *On the* Genus *Loxonema, with* Descriptions *of* New Proterozoic Species. By Jane Longstaff (*née* Donald), F.L.S. (Communicated by Dr. G. B. Longstaff, M.A., F.G.S. Read January 13th, 1909.)

[Plates X & XI.]

There is considerable confusion with regard to the genotype of *Loxonema*, Phillips. This has arisen because Phillips did not fix a genotype himself, and because he confounded a Devonian form with his first-mentioned species. This last is the Silurian *Terebra (?) sinuosa* of Sowerby.[1] Both the Devonian form which Phillips calls *Loxonema sinuosum* and Sowerby's holotype bear the characteristics of the genus as defined by him, but they certainly are specifically distinct. The genus was founded by Phillips in 1841;[2] and, though I have given the original diagnosis in a former paper, it seems advisable to reproduce it here:—

'Spiral, turriculated; whorls convex, their upper edges adpressed against the next above; without spiral band; mouth oblong, attenuated above, effused below, with a sigmoidal edge to the right lip; no umbilicus (?); surface covered by longitudinal threads or ridges, generally arched.

'These observations are merely provisional until the form of the aperture is more perfectly known. The shells have been placed as *Melania*, *Rissoa*, *Terebra*, *Turritella*, and *Scalaria*.

'In regard to the number of species mentioned, I must observe that I find it impossible to do otherwise than preserve the names of all as distinct varieties; but that it is very probable most of them are only varieties of three or four types, one having *L. sinuosa* for one extremity and *L. Hennahii* for the other; a second related to *L. tumida* and *L. lincta*; a third to *L. rugifera*. Count Münster's figures referred to are certainly of Devonian species.' (*Op. cit.* pp. 98-99.)

A. d'Orbigny appears to have been the first to notice the error in identification,[4] for he enters the Silurian form as

'*sinuosa*, d'Orb., 1847. *Terebra sinuosa*, Sow., 1839 in Murch. Silur. Syst., pl. 8, fig. 15. Angleterre, Ludlow-Rock'

and the Devonian one as

'*Phillipsii*, d'Orb., 1847. *L. sinuosa*, Phill., 1841. Pal. Foss., pl. 38, fig. 182; *Tereb. id.* (non *sinuosa*), Sow. Sil. Syst. pl. 8, fig. 15. Angleterre, Petherwin,'

but does not make any remarks.

M'Coy[5] evidently considers the Devonian distinct from the Silurian form: for, when describing *L. nexilis*, Sow. he writes thus:

'I should think the S. Petherwin shell figured and described by Phillips, Pal. Foss., as the Silurian *Terebra sinuosa* of Sowerby, belongs to the present species.'

They are not, however, conspecific (see pp. 212 & 217).

Lindström points out, in his synonymy of *L. sinuosum*, Sow.,[6]

[1] 'Silurian System' 1839, p. 619 & pl. viii, fig. 15.
[2] 'Pal. Foss. of Cornwall, Devon, &c.' p. 98.
[3] Quart. Journ. Geol. Soc. vol. lx (1905) p. 564.
[4] 'Prodrôme de Paléont. Strat.' vol. i (1850) pp. 29 & 62.
[5] 'Brit. Pal. Foss.' 1855, p. 399.
[6] 'Silur. Gastr. & Pter. Gotland' Kongl. Svensk. Vetensk.-Akad. Handl. n. s. vol. xix (1884) no. 6, p. 142.

that it is distinct from the Devonian shell so named by Phillips. Mr. Whidborne,[1] however, thinks them identical. There is no doubt, nevertheless, about their being different, and the question therefore arises as to the shell upon which Phillips founded his diagnosis, since that must be regarded as the genotype.

It has been suggested to me that Phillips must have intended the Devonian form which he had by him as the genotype; but, as he does not clearly state this, he leaves it to those who follow to decide the matter. He quotes '*L. sinuosa*' as the first 'type' before he gives the specific description of his shell; therefore he must evidently refer to Sowerby's form, but his generic description is probably founded on both shells. Succeeding palæontologists have adopted the name *L. sinuosum* as the genotype, though not always stating which form they meant, for most of them evidently did not realize that two distinct shells were indicated by one name. This seems to have been the case with both S. P. Woodward and P. Fischer. The former[2] quotes as type '*L. sinuata*, U. Devonian, Petherwin,' without stating to whom the species is referable. When F. Schmidt[3] mentions *L. sinuata* he evidently means *L. sinuosum* (Sow.), as he refers to the figure of that shell in the 'Silurian System,' and it is highly probable that Woodward does the same. Fischer[4] gives for type '*L. sinuosum*, Sow. Dévonien.' Those who have most deeply studied the Palæozoic Gasteropoda, such as Lindström, Koken, and Perner, appear to have taken it for granted that *L. sinuosum* (Sow.) was the genotype, for they do not discuss the claim of the Devonian form to be considered as such. It seems advisable to follow their example, as likely to cause least confusion: for, if the Devonian shell were substituted, it would necessitate the introduction of a new name for the genotype and upset much good work.

If *L. sinuosum* (Sow.) be regarded as the genotype of the genus *Loxonema* sensu stricto, it is clear that the other two 'types' mentioned by Phillips cannot remain in the genus. The second 'type' is represented by *L. tumidum* and *L. linctum*; the latter species belongs to the genus *Macrochilina*, Bayle.[5] Two distinct species are named *tumida* by Phillips, one Carboniferous, the other Devonian. The former as represented in the figure[6] does not appear to have had sigmoidal lines of growth. The holotype is not in the Gilbertson Collection at the British Museum, and the only specimen contained in that collection has not the surface preserved. I have not been able to find the holotype of the Devonian form; but, judging by the figure,[7] it is very different from *L. sinuosum* in character.

[1] 'Devonian Fauna of the South of England' pt. iii, Monogr. Palæontogr. Soc. vol. xliv (1890–91) p. 176.

[2] 'A Manual of the Mollusca' 2nd ed. (1871) p. 141.

[3] Archiv für die Naturkunde Liv- Ehst- & Kurlands' ser. 1, vol. ii (1858) p. 202.

[4] 'Manuel de Conchyliologie & de Paléontologie Conchyliologique' 1885, p. 696.

[5] Whidborne, *op. supra cit.* p. 163.

[6] 'Illustr. Geol. Yorks.' vol. ii (1836) pl. xvi, fig. 2 & p. 229.

[7] 'Pal. Foss. Cornwall, &c.' 1841, pl. xxxviii, fig. 186 & p. 223.

L. rugiferum, the third 'type,' is also represented by two forms, one Carboniferous and the other Devonian. The latter received the name *L. anglicum* from A. d'Orbigny,[1] and the former was described as *Melania rugifera* by Phillips.[2] Although both these shells belong to the family Loxonematidæ, they cannot be referred to the genus *Loxonema* s. s., but must find a place in the subgenus *Zygopleura*, Koken.[3]

Not only has Phillips associated with *Loxonema* several forms which do not bear the characteristics of the genus as defined by him, but succeeding palæontologists have done the same. Prof. Koken, however, and several recent authors, perceiving this error, have created new genera and subgenera for these shells. As this paper simply deals with Ordovician and Silurian species, but few subgenera need be mentioned: these are *Rhabdostropha*, Donald,[4] and *Stylonema*, Perner.[5]

It is possible that a distinct group should be made for such forms as the Devonian *L. sinuosum*, Phill. (*cornubicum*), *L. nexile* (Sow.), *L. hennahianum* (Sow.), etc., having more flattened whorls strongly adpressed at the suture, with an angularity on the body-whorl, and coarser and less strongly-bent lines of growth than the genotype.

Genus Loxonema, Phill. emend.

Diagnosis.—Shell elongated, turriculated, consisting of numerous whorls. Whorls convex or slightly flattened, their upper edges adpressed against the next above. No spiral band; ornamentation consisting of sigmoidal lines or threads. Aperture oblong, attenuated above, effused below, outer edge sigmoidal. No umbilicus.

Genotype, *Loxonema sinuosum*, Sow.

Dimensions.—The British Proterozoic species range from about 20 to about 65 millimetres in length.

Remarks and relationship.—It is always difficult to ascertain the affinities of Palæozoic families, owing to the imperfect preservation of their representatives, and to this the Loxonematidæ are no exception. The earlier palæontologists placed the genus *Loxonema* in different families, such as the Pyramidellidæ, Euomphalidæ, or Pseudomelaniidæ, according to their several views of its affinities. Prof. Koken considers that it and several closely allied genera should, constitute a distinct family, and most recent palæontologists follow his example. He also thinks that *Loxonema*, *Murchisonia*, and *Ectomaria* are nearly related. The typical *Loxonema* certainly bears great resemblance to some of the genera and subgenera into which the Murchisoniidæ have been divided; and more especially to *Hormotoma* (where the whorls are smooth and the lines of growth may be traced from suture to suture), but this genus differs in having

[1] 'Prodr. Paléont. Strat.' vol. i (1850) p. 62.
[2] 'Illustr. Geol. Yorks.' vol. ii (1836) p. 229 & pl. xvi, fig. 26.
[3] 'Die Leitfossilien' Leipzig, 1896, p. 108.
[4] Quart. Journ. Geol. Soc. vol. lxi (1905) p. 565.
[5] 'Syst. Sil. Centre Bohême,' pt. i, vol. iv, Gastéropodes, par J. Perner, tome ii (1907) p. 325.

a sinual band. The likeness to *Ectomaria* is much less, for though the lines of growth continue without break, the whorls are lower and are ornamented by keels. *Loxonema* is further distinguished from both these genera in having a comparatively shallow, instead of a deep tongue-shaped sinus. Dr. Perner describes a new genus under the name of *Sinuspira*, which he considers intermediate between *Ectomaria* and *Loxonema*; it resembles the latter in form and in having smooth whorls, but it has a much deeper sinus. In this character it is like both *Ectomaria* and *Hormotoma*, and more especially the latter, as the lines are similarly curved instead of being straight as in the former. It is distinguished from *Hormotoma* by not possessing so distinctly defined a band, and from *Ectomaria* by having high and smooth whorls.

In this country *Ectomaria* appears to make the earliest appearance, occurring in the Durness Limestone,[1] where it is represented by *E. pagoda*, Salt. var. *peachii*, Don. and var. *orientalis*, Don., and by *E. antiqua*, Don.[2] *Hormotoma* was recorded from the same horizon,[3] but I am informed that a mistake was made with the label of *H. salteri*, Ulrich & Scofield, when the specimens were sent to me from the Edinburgh Museum, as they were really from Canada. The other two species from Durness are only referred to the genus with a query. I have not met with undoubted species of *Hormotoma* earlier than the Llandeilo formation. *Loxonema*, so far as I know at present, appears first in rocks of Bala age.

In America both *Hormotoma* and *Ectomaria* are recorded from the Calciferous Formation (Tremadoc). They do not seem to be known earlier than the Bala in the Baltic Provinces of Russia. The earliest species referred to *Loxonema* in America are *L. murrayanum*, Salt. and *L. jerseyense*, Weller, both from the Trenton: neither of them is represented as having the lines of growth characteristic of *Loxonema*. In Sweden, *Loxonema dalecarlicum*, Lindstr. is recorded from the *Leptæna*-Kalk (Upper Bala?); it greatly resembles the British species *L. striatissimum*, Salt., from the Upper Bala, and *L. grayianum*, from the Lower Llandovery.

Thus, it may be observed that, judging from our present evidence, *Loxonema* appeared later than either *Ectomaria* or *Hormotoma*. Also there is no evidence of *Loxonema* being derived from either of these genera, though they may all have originated from a common stock; as yet, however, we have not sufficient material to afford grounds for the establishment of such a theory. It is possible that *Ectomaria* and *Hormotoma* may each have had a distinct line of ancestry, if the former be a primitive relation of the Turritellidæ, as has been surmised by Ulrich & Scofield. The recent Turritellidæ, however, show no trace of primitive origin and are Tænioglossa; while the Murchisoniidæ are supposed to have been Rhipidoglossa, on account of their resemblance to the recent Pleurotomariidæ, which have distinctly primitive characters.

[1] Quart. Journ. Geol. Soc. vol. lv (1899) pp. 254 & 270.
[2] *Ibid.* vol. lviii (1902) p. 319.
[3] *Ibid.* vol. lv (1899) p. 262.

It is somewhat remarkable that the most deeply sinuated species of *Loxonema*, such as *L. sinuosum* (Sow.) and *L. intumescens*, Lindstr., as well as the only described species of *Sinuspira*, Perner, and the spirally striated subgenus *Rhabdostropha*, occur in the higher Proterozoic strata. As these forms seem to come nearest in appearance to the Murchisoniidæ, we might have expected them to occur earlier.

Range.—Species have been referred to this genus from the Ordovician up to the Lias; but most of those placed here subsequent to the Carboniferous and also some occurring in that formation do not belong to the genus *sensu stricto*.

The British Proterozoic species range from the Bala up to and throughout the Ludlow Formation. Besides the genotype *L. sinuosum* (Sow.), there have been described four other species, namely, *L. elegans*, M'Coy, from the Lower Ludlow, *L. striatissimum*, Reed, from the Upper Bala, *L. grindrodi*, Don., from the Lower Ludlow, and *L. pseudofasciatum*, Don., from the Wenlock Limestone. The two latter do not belong to *Loxonema* s. str., but have been placed in the subgenus *Rhabdostropha*, Don. The holotype of *L. elegans*, M'Coy, is in the Sedgwick Museum, Cambridge, and is too badly preserved to make out the structure sufficiently to refer any other shell to the species. In addition to these, I am here describing as new to Britain seven species and one variety of *Loxonema* s. str., one species of *Rhabdostropha*, and two species probably referable to *Stylonema*. Further, I am giving the description of a new species of *Hormotoma* from the Llandeilo Formation, as it is the oldest undoubted representative of the genus at present known to me in Britain.

Lindström records six Proterozoic species from Sweden, namely, *L. dalecarlicum*, Lindstr., from the *Leptæna*-Limestone, and *L. sinuosum* (Sow.), *L. attenuatum*, Lindstr., *L. intumescens*, Lindstr., *L. strangulatum*, Lindstr., and *L. (?) fasciatum*, Lindstr., from the Silurian. Through the kindness of Prof. Gerhard Holm I have been enabled to compare the Gothlandic with the British forms, and I find that *L. intumescens* is the only species that appears to be represented in Britain. The *L. sinuosum* of Lindström is quite distinct from that of Sowerby—the whorls being more excavated above and more convex below, and the sinus being situated lower down; it also occurs on a lower horizon. It must, therefore, be regarded as a new species, for which I suggest the name *L. lindströmii*. *L. attenuatum* has a narrow and faintly limited band, and seems closely allied to the species referred by Dr. Perner to the subgenus *Goniospira*, Donald[1] (*Donaldiella*, Cossmann)[2], more especially to *D. gracillima*, (Barr.). This shell has not so prominent a band as the type, *D. filosa*, Don. *Loxonema (?) fasciatum* probably belongs to the genus *Sinuspira*, Perner.

The family is more richly represented in Bohemia, where Dr. Perner records twenty-five species from the Silurian, eight

[1] Quart. Journ. Geol. Soc. vol. lviii (1902) p. 328.
[2] 'Revue de Paléozoologie' vol. vii (1903) p. 68.

of which he refers to *Loxonema* s. str. and seventeen to *Stylonema*. All of these occur in E. e 2 except one, namely, *L. (Stylonema) libens*, Barr., which is from E. e 1. None of the Bohemian species appear to be represented either in Britain or in Scandinavia.

In America two Ordovician and about thirteen Silurian species are recorded, but few are sufficiently well represented to show whether they really belong to the genus *sensu stricto*.

Loxonema sinuosum (Sow.). (Pl. X, figs. 1 *a* & 1 *b*.)

Terebra (?) sinuosa, J. de C. Sowerby, 1839, 'Silurian System' p. 619 & pl. viii, fig. 15.
Loxonema sinuosum (Sow.), J. Phillips, 1841, 'Pal. Foss. Cornwall, Devon, &c.' p. 98, *non* p. 99 & pl. xxxviii, fig. 182.
Non *Terebra (?) sinuosa* (Sow.), J. W. Salter, 1848, Mem. Geol. Surv. vol. ii, pt. i, p. 357 & pl. xiv, fig. 2.
Loxonema sinuosum pars, H. G. Bronn, 1848, 'Index Palæont.' p. 670.
Terebra sinuosa, T. Brown, 1849, 'Illustr. Foss. Conch. Great Brit. & Irel.' p. 251 & pl. xxxiii*, fig. 62.
Loxonema sinuosum, A. d'Orbigny, 1850, 'Prodr. Paléont. Strat.' vol. i, p. 29.
Loxonema sinuosum, J. Morris, 1854, 'Catal. Brit. Foss.' p. 255.
? *Loxonema sinuatum*, F. Schmidt, 1858, Archiv für die Naturkunde Liv- Ehst- & Kurlands, ser. 1, vol. ii, p. 202.
Loxonema sinuosum, J. Sowerby, 1867, 'Siluria' 4th ed. p. 532 & pl. xxiv, fig. 3.
Loxonema sinuosum pars, J. J. Bigsby, 1868, 'Thes. Sil.' p. 156.
? *Loxonema sinuatum*, S. P. Woodward, 1871, 'A Manual of the Mollusca' 2nd ed. p. 141.
? *Loxonema sinuosum*, J. W. Salter, 1873, 'Catal. Cambr. & Silur. Foss.' p. 172.
Loxonema sinuosum, A. C. Ramsay, 1881, 'Geology of N. Wales' Mem. Geol. Surv. 2nd ed. p. 468.
Loxonema sinuosum, J. D. La Touche, 1884, 'Geol. of Shropshire' p. 49 & pl. xviii, fig. 637.
Non *Loxonema sinuosum*, G. Lindström, 1884, 'Silur. Gastr. & Pter. Gotland' Kongl. Svensk. Vet.-Akad. Handl. n. s. vol. xix, no. 6, p. 142 & pl. xv, figs. 1–5, 7.
Loxonema sinuosum, P. Fischer, 1885, 'Manuel de Conchyliologie & de Paléontologie Conchyliologique' p. 696.
Loxonema sinuosum, R. Etheridge, 1888, 'Foss. Brit. Is.' vol. i (Pal.) p. 112.
Loxonema sinuosum, E. Koken, 1896, 'Die Leitfossilien' pp. 106, 458 (*non* p. 515).
? *Loxonema sinuosum*, J. Horne & B. N. Peach, 1899, Mem. Geol. Surv. 'Silur. Rocks of Brit.' vol. i, p. 682.
? *Loxonema sinuosum*, B. N. Peach, J. Horne, & A. Macconochie, 1901, in 'Fauna, Flora & Geol. of Clyde Area,' publ. by local Comm. for Meeting of Brit. Assoc. (Glasgow) p. 438.

Diagnosis.—Shell subulate; whorls more than four, increasing at a moderate rate, smooth, slightly convex, but little adpressed at the suture. Lines of growth fine, sharp, strongly sigmoidal, indicating an almost right-angled sinus in the outer lip; greatest sinuosity near the middle of the whorl. Aperture not visible.

Remarks and resemblances.—The holotype is in the Museum of the Geological Society of London (R 6695); it is partly embedded in the matrix, and only four whorls are preserved. It is remarkable for having the lines of growth so strongly bent as almost to form a right angle near the middle of the whorl. The shell is slightly broken immediately below the suture of the body-whorl, and the earlier whorls are merely represented by an internal mould, therefore the adpression at the suture is not well shown. I have previously pointed out [1] that Salter made a mistake in referring

[1] Quart. Journ. Geol. Soc. vol. lv (1899) p. 265.

a very different form to this species. Through the courtesy of Prof. Hughes I have seen another specimen also placed here by Salter; it is in the Sedgwick Museum $\left(\frac{b}{926}\right)$, comes from the Lower Ludlow of Dudley, and is really in too poor a condition to make anything of. Prof. Holm has kindly enabled me to compare the shell named *Loxonema sinuosum* (Sow.) by Lindström with the type, and I find it quite distinct, the whorls being more concave above, more convex below, and the sinus situated lower. The form of the lines of growth greatly resembles that of *L. intumescens*, Lindstr., but the contour of the whorls is different. A Bohemian shell described by Barrande as *L. beraunense*[1] was afterwards referred by him to this species; Dr. Perner, however, considers it distinct, and restores Barrande's name.

Dimensions.—The length of the holotype (Pl. X, figs. 1*a* & 1*b*) = 29 millimetres; the width = 10 mm.

Locality.—Garden House Quarry, Aymestry.

Horizon.—Lower Ludlow.

LOXONEMA CORNUBICUM, sp. nov. (Pl. X, figs. 2*a* & 2*b*.)

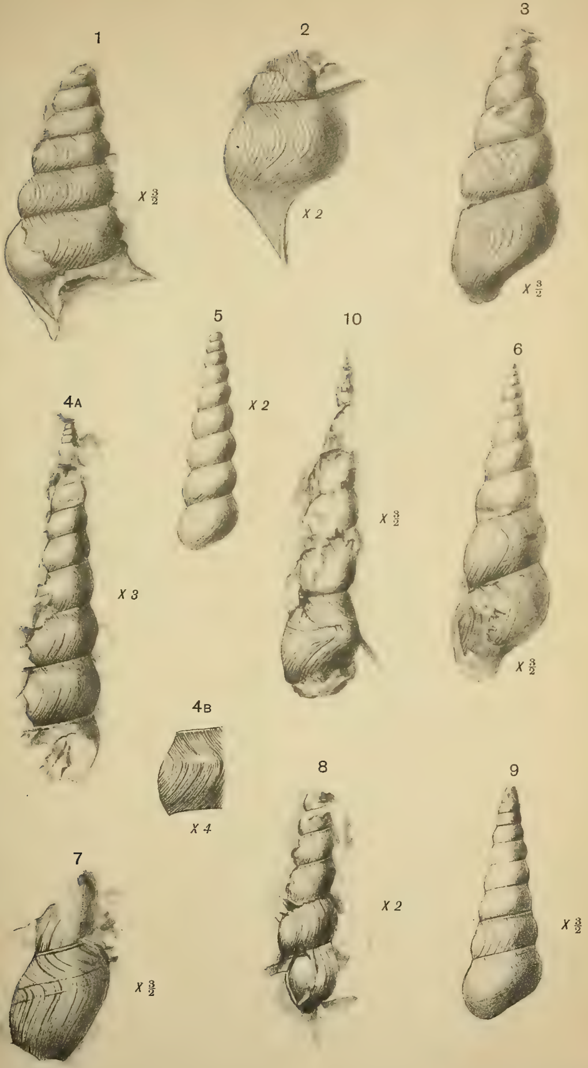
Loxonema sinuosum, J. Phillips, 1841, 'Pal. Foss. Cornw. Dev. & W. Somerset' p. 99 (*non* p. 98) & pl. xxxviii, fig. 182. (Non *Terebra* (?) *sinuosa*, J. de C. Sowerby, 1839, 'Sil. Syst.' p. 619 & pl. viii, fig. 15.)
Loxonema sinuosum pars, H. G. Bronn, 1848, 'Index Palæont.' vol. i, p. 670.
Loxonema Phillipsii, A. d'Orbigny, 1850, 'Prodr. Paléont. Strat.' vol. i, p. 62. (Non *L. Phillipsii*, Rœmer, 1843, 'Verstein. des Harzgebirges' p. 30 & pl. viii, fig. 9.)
Loxonema sinuosum, J. Morris, 1854, 'Catal. Brit. Foss.' p. 255.
Loxonema sinuosum, J. J. Bigsby, 1878, 'Thes. Dev.-Carb.' p. 83.
Loxonema sinuosum, R. Etheridge, 1888, 'Foss. Brit. Is.' vol. i (Pal.) p. 163.
Loxonema sinuosum, E. Koken, 1896, 'Die Leitfossilien' p. 515.

Diagnosis.—Shell subulate. Whorls more than four, increasing at a moderate rate, flattened, very slightly convex, strongly adpressed at the suture, high, smooth; body-whorl subangular below. Lines of growth strong, with some finer lines intercalated, sigmoidal, greatest sinuosity near the middle of the whorl, widely concave. Aperture imperfectly known, longer than wide. No umbilicus.

Remarks and resemblances.—The holotype (No. 7074) is the specimen supposed to be that described and figured by Phillips[2] as *L. sinuosum*, which is in the Museum of Practical Geology, Jermyn Street. A query as to its being really Phillips's type has been inserted on the label, probably because this shell is disengaged from the matrix, and Phillips's figure is represented as embedded. The fact of its having a little of the rock adhering to the sides may have led the artist to represent it in this manner; in other respects the specimen agrees with the figure, and has a similar breakage on the body-whorl. Another, but less perfect

[1] 'Syst. Sil. Centre Bohême' pt. i, vol. iv, Gastéropodes, par J. Perner, tomes i & ii (1903 & 1907) pl. lx, figs. 18–19, with text-figs. 236–238 & p. 327.

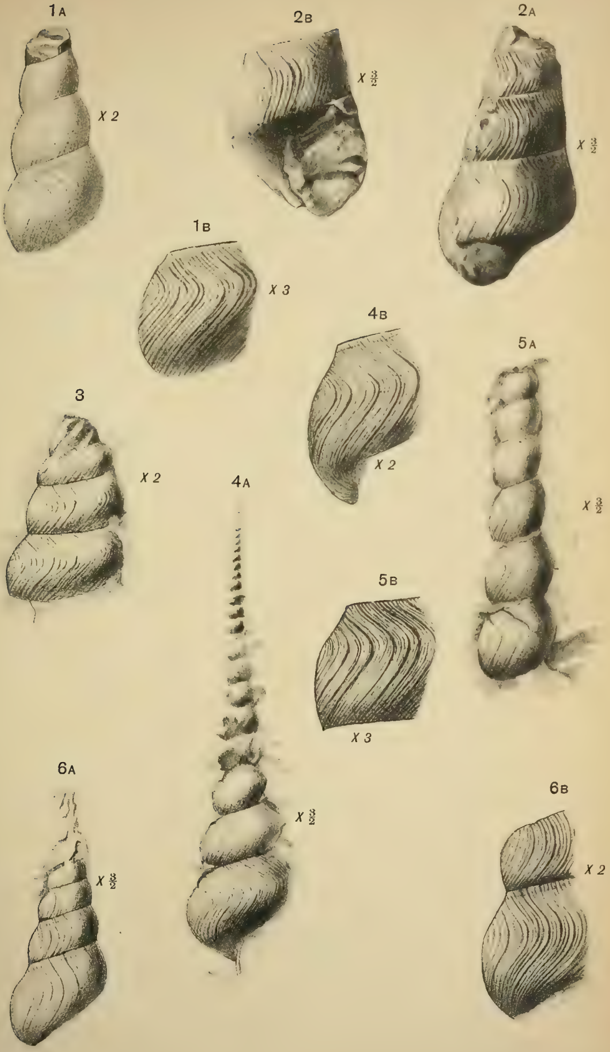
[2] 'Pal Foss. Cornwall, &c.' 1841, p. 99 & pl. xxxviii, fig. 182.



J. Longstaff, del.

Bemrose, Collo., Derby.

LOXONEMA.



J. Longstaff, del.

Bemrose, Collo., Derby.

LOXONEMA.

example (No. 21074), is associated with it. There is also a well-preserved specimen (G 32954) in the British Museum (Natural History). *L. cornubicum* may be distinguished from the Silurian *L. sinuosum* (Sow.), with which Phillips confounded it, by the whorls being higher, flatter, and more adpressed at the suture, and by the lines of growth forming strong raised threads, and not being so sharply bent. A. d'Orbigny called this species *L. phillipsii*, but the name cannot stand, as it had previously been used to designate another gasteropod by Rœmer. M'Coy[1] considers the larger specimen figured by Sowerby[2] as *Terebra nexilis* to be identical with this species. It differs, however, by being more slender and by the lines of growth being less curved.

Dimensions.—The holotype (Pl. X, figs. 2 *a* & 2 *b*) consists of only three and a half whorls, as the apex is broken; its length = 31·5 millimetres, and its width = 16·5 mm.

Locality.—South Petherwin (Cornwall).

Horizon.—Middle Devonian.

LOXONEMA INTUMESCENS (?) Lindstr. (Pl. X, fig. 3.)

Loxonema intumescens, G. Lindström, 1884, 'Silur. Gastrop. & Pterop. Gotland Kongl. Svensk. Vet.-Akad. Handl. n. s. vol. xix, no. 6, p. 143 & pl. xv, fig. 6.

Diagnosis.—Shell composed of more than nine gradually increasing whorls. Whorls flattened above, convex below, having a high-shouldered appearance. Lines of growth forming sharp raised threads, varying in strength, some being stronger than others at irregular intervals, curving very obliquely backward above and forward below, making an almost right-angled sinus slightly above the middle of the whorl. Aperture unknown.

Remarks and resemblances.—Through the kindness of Prof. Holm I have been enabled to compare Lindström's holotype with a specimen (G 15699) in the Piper Collection in the British Museum (Natural History). This latter shell is so embedded in the matrix that portions of only four whorls are visible, and it is much crushed. Despite its imperfect state of preservation, I think that it is probably identical with the Gothlandic species. The whorls of both have a high-shouldered appearance, and the lines of growth are similar; the chief distinction lies in the whorls of the British specimen being broader, but this seems to have arisen from pressure. The whorls do not appear to be adpressed at the suture, either in the British or in the Gothlandic specimens; but none are well preserved, and therefore we cannot be certain of the absence of this feature. This species differs from *Loxonema sinuosum* (Sow.) in the form of the whorls, which are more prominently convex, and in the sinus being situated higher. Dr. Perner considers *L. inexpectatum*, Barr.,[3] somewhat like *L. intumescens*, Lindstr., but the form of the whorls is different. The contour of the

[1] 'Brit. Pal. Foss.' 1855, p. 399.

[2] Trans. Geol. Soc. ser. 2, vol. v, pt. iii (1840) pl. liv, fig. 17 & p. 703*.

[3] 'Syst. Sil. Centre Bohême' pt. i, vol. iv, Gastéropodes, par J. Perner, tomes i & ii (1903 & 1907) p. 330 & pl. lx, fig. 13.

whorls of *L. costulatum*, Pern.,[1] resembles that of the species under discussion, but there the sinus is situated still higher. In the Oxford University Museum are two specimens of this species; both are crushed and embedded in the matrix. The largest gives evidence of having possessed more than nine whorls; on three of these the characteristic lines of growth are preserved, but the shell is so contorted obliquely that the form of the whorls is not well shown. The other example is an internal mould consisting of four whorls. There is also a smaller and apparently more slender shell, which is not so much crushed as the others; it is, however, deeply embedded in the matrix, and its state of preservation prevents it from being referred to this species with certainty.

Dimensions.—The fragment of three and a half whorls figured (Pl. X, fig. 3) measures 16 millimetres in length, and the width = 10 mm. This latter measurement is probably greater than it must originally have been, on account of the specimen being so much crushed. The largest shell in the Oxford University Museum has nine whorls, and is 33 millimetres long. The specimen figured by Lindström consists of six whorls, which are 32 mm. in length and 14 mm. in width.

Locality and horizon.—Ledbury, in the Lower Ludlow. Lindström states that it is found in the Upper Limestone near Wisby, and also at Westergarn.

Loxonema latouchei, sp. nov. (Pl. X, figs. 4 *a* & 4 *b*.)

Diagnosis.—Shell greatly elongated. Whorls more than twenty-two in number, smooth, convex, slightly flattened above, adpressed at the suture. Lines of growth very fine and close together, sweeping obliquely backward above and forward below, forming almost a right angle near the middle of the body-whorl, but below the middle of the penultimate whorl, less strongly bent on the penultimate and earlier whorls, and thus making a wider curve on them. Aperture elongated, imperfectly known.

Remarks and resemblances.—There are five specimens of this species in the collection of the Rev. W. M. D. La Touche, one of which is represented by both external and internal moulds; both these and two of the others have the surface well preserved. The Manchester Museum contains two specimens in the Watson Collection. All the shells are partly embedded in the matrix and somewhat crushed; those in the latter collection are so preserved as to have the sutures more oblique than the others. *L. latouchei* may be distinguished from all other British species by its great length and numerous whorls, which characteristics, associated with the strongly bent lines of growth, also separate it from all the Gothlandic and Bohemian species described by Lindström and Perner. It may possibly be *L. elegans*, M'Coy,[2] but the holotype

[1] *Op. cit.* tome ii, p. 328 & text-fig. 239.
[2] 'Brit. Pal. Foss.' 1855, p. 302 & pl. i K, fig. 34.

of that species in the Sedgwick Museum shows no structure, and is too imperfectly preserved to admit of a satisfactory comparison; also the lines of growth as represented in the figure are much more slightly curved. The lines of growth on *L. latouchei* resemble those of *L. sinuosum* (Sow.) in form, but the greatest sinuosity is situated lower on the whorl.

Dimensions.—The holotype is the longest specimen in Mr. La Touche's collection: it consists of twenty-two whorls in a length of 55 millimetres; the width = 13 mm. (Pl. X, fig. 4 *a*). A shell in the Manchester Museum gives evidence of having possessed eighteen whorls, which measure 65·5 mm. in length and about 13 mm. in width. A single whorl of this specimen is figured on Pl. X, fig. 4 *b*.

Locality.—All the specimens are from Stoke Wood Quarry.

Horizon.—Lower Ludlow.

Loxonema ledburiense, sp. nov. (Pl. X, figs. 5 *a* & 5 *b*.)

Diagnosis.—Shell very elongated, slender. Whorls more than ten in number, increasing gradually, flattened or slightly concave above, prominently convex below. Lines of growth distinct, fine, close together, with stronger lines at irregular intervals, curving very obliquely backward above and forward below, forming an almost right-angled bend high up on the whorl. Sutures oblique. Aperture longer than wide, imperfectly known.

Remarks and resemblances.—The holotype is in the Oxford University Museum; it is embedded in the matrix and neither apex nor base are preserved, but the surface is tolerably well seen. Two other specimens associated with it from the same locality are probably identical; but they are much crushed internal and external moulds, and no lines of growth are visible. There is also an example (No. 21070) in the Museum of Practical Geology which greatly resembles this in its slender form and in the high position of the sinus. It is flattened by pressure, and, although embedded in the matrix, gives evidence of having possessed more than ten whorls. This species is distinguished from *L. latouchei* by its more convex whorls, the higher position of the sinus, and by its probably more slender form. It differs from *L. intumescens*, Lindstr., in having higher whorls, a broader sinus, and finer lines of growth.

Dimensions.—The holotype figured (Pl. X, figs. 5 *a* & 5 *b*) measures 36 millimetres in length, and the greatest width exposed is 9 mm. The shell in the Museum of Practical Geology is 40 mm. long.

Locality and horizon.—The holotype and the moulds associated with it are from the Lower Ludlow of Ledbury. The specimen in the Museum of Practical Geology, Jermyn Street, is from the Upper Ludlow; the locality is not quite certain, Ludlow being only surmised.

Loxonema planatum, sp. nov. (Pl. X, figs. 6 *a* & 6 *b*.)

Diagnosis.—Shell composed of more than eight whorls. Whorls smooth, increasing gradually, so closely adpressed at the suture as to give rise to a flattened band, convex below. Lines of growth distinct, fine with occasional stronger lines intercalated, sigmoidal, more strongly curved on the body-whorl than on the whorls of the spire, greatest sinuosity submedian. Sutures oblique. Base convex, somewhat produced.

Remarks and resemblances.—All the specimens of this species known to me are so greatly compressed that the whorls appear wider than they must originally have been. The depth and height of the sinus vary slightly on different individuals. The specimen figured in Pl. X, fig. 6 *b*, has the sinus on the body-whorl rather deeper than that on any of the others. *L. planatum* is distinguished from *L. sinuosum* (Sow.) by the whorls being more flattened and more adpressed at the suture above; by the lines of growth being less sharply bent near the middle of the whorl; and by a more marked difference in the amount of this sub-central bend on the body-whorl from that on the whorls of the spire. It somewhat resembles *L. latouchei*; but it is shorter, and the lines of growth are different.

Dimensions.—The holotype (G 4656) figured (Pl. X, fig. 6 *a*) is in the British Museum (Natural History). It consists of four whorls and the impression of four others, in a length of 28 millimetres; the greatest width is 13 mm., but measured in the opposite direction it would be much less, on account of the pressure to which the shell has been subjected. The example in the Oxford University Museum (fig. 6 *b*), of which portions of the penultimate and body-whorls are reproduced, consists of only these two whorls which are 18 mm. in length; the greatest width is 14 mm., and in the opposite direction it is only 6 mm. on account of the specimen being compressed. A fragment which is in Sir Charles Holcroft's collection must have been part of a much larger shell; it consists of three whorls, which have a total length of 38 millimetres.

Locality and horizon.—There are two specimens (G 4637 & 4656) in the British Museum (Natural History) and two in the Oxford University Museum, all from the Wenlock of Garcoed, Usk, Monmouth. The latter Museum also contains two examples from the Upper Ludlow, and an obliquely compressed shell which is probably this species from the Lower Ludlow of Ledbury. In the Museum of Practical Geology, Jermyn Street, there are three specimens (Nos. 21064, 21065, & 21068) from the Lower Ludlow of Ledbury and two (Nos. 21072 & 21073) from the Upper Ludlow of the River Wye near Erwood, but none of these are well preserved. The Worcester Museum contains two very imperfect shells collected by the late Mr. G. Reece, each consisting of about two and a half whorls, from the 'Woolhope or Wenlock Shale Series' of the Malvern Hill Tunnel, which probably belong to this species. Mr. Madeley has a specimen which is more like this species than any other: three whorls are partly visible, and the lines of

growth may be seen on two of them; the state of preservation is too bad for certain identification. It occurred in the shale at the top of the Wenlock Limestone, Dudley. There is also an example of this species in Sir Charles Holcroft's collection from the Wenlock Shale, Dudley; although it is much crushed, the surface is well preserved.

LOXONEMA PERNERI, sp. nov. (Pl. XI, fig. 1.)

Diagnosis.—Shell composed of more than seven whorls. Whorls increasing gradually, but slightly adpressed at the suture, smooth, very convex. Lines of growth fine, sharp, and distinct, forming a wide sinus near the middle of the whorl. Sutures slightly inclined. Base convex, produced. No umbilicus.

Remarks and resemblances.—This species differs from *L. sinuosum* (Sow.) in having more convex whorls, deeper sutures, and in the lines of growth making a broader submedian bend. It is distinguished from *L. planatum* in the whorls being more convex and less flattened above, and in the sutures being less oblique; also the curve of the lines of growth increases more gradually on the whorls of the spire.

Dimensions.—The holotype figured (Pl. XI, fig. 1) consists of six whorls in a length of 30 millimetres, and measuring 14·5 mm. in width. The shell is embedded in the matrix, and so flattened by pressure that it appears broader than it must originally have been.

Locality and horizon.—In the Museum of Practical Geology are two specimens, one (the holotype) (No. 21069) from the Upper Ludlow of Ludlow (Pl. XI, fig. 1), the other (No. 21063) from the Lower Ludlow of Round Hill (Worcestershire). The Oxford University Museum contains two examples from Ledbury: one is represented by both external and internal moulds for which no horizon is given, the other is from the Lower Ludlow. Mr. Madeley has the external and internal moulds of a specimen, consisting of about twelve whorls, which probably belongs to this species, but it is not well enough preserved for certain identification; it is from the shale at the top of the Wenlock Limestone, Dudley.

LOXONEMA PERNERI, var. DUDLEYENSE, nov. (Pl. XI, figs. 2 & 3.)

There is a well-preserved fragment (Pl. XI, fig. 2) of a shell (G 15700) in the Piper Collection in the British Museum (Natural History), which is very slightly crushed and stands out convex from the matrix. The lines of growth form a somewhat wider sinus on the body-whorl, and curve back rather less obliquely above than in the type. Only the body-whorl and a portion of the penultimate exist, measuring 19 millimetres in length and 10·5 mm. in width. It is from the Lower Ludlow of Ledbury Tunnel.

A specimen (No. 21066) in the Museum of Practical Geology is closely akin to this; the lines of growth are similar in form, being less strongly curved than in the typical *L. perneri*; they are also coarser and less closely packed. The shell is embedded in the

matrix, and so much crushed that a just comparison is impossible. It consists of six whorls in a length of 32 millimetres, the greatest breadth being 12 mm. This example (Pl. XI, fig. 3) is from the Lower Ludlow of Dudley.

At present, this may be regarded as a variety of *L. perneri.* The discovery of more specimens may prove it to be a distinct species ; while, on the other hand, they may form links connnecting it with the type.

The example in the Piper Collection is regarded as the holotype.

Loxonema grayianum, sp. nov. (Pl. XI, fig. 5.)

Diagnosis.—Shell small, very slender, composed of more than nine whorls. Whorls flattened or slightly concave above, convex below. Sutures deep, very oblique. Lines of growth fine, curving slightly backward above and more strongly forward below. Aperture unknown. Base convex.

Remarks and resemblances.—This species is remarkable for its small size and slenderness. In these respects it bears a great resemblance to species of *Aclisina,* but is devoid of the characteristic spiral ornamentation of that genus. It is distinguished from *L. reedi* in the whorls being less concave above and the lines of growth not curving so obliquely backwards. It is most like the drawing of *L. dalecarlicum*, Lindstr.,[1] given by Prof. Koken in 'Die Gastrop. des Baltischen Untersilurs' Bull. Acad. Imper. Sci. St. Petersb. ser. 5, vol. vii (1897) no. 2, p. 202, fig. 40, but the whorls are more flattened above, and the lines of growth advance more obliquely forward below. It differs from *Holopella tenuicincta*, M'Coy,[2] in having the whorls flattened above instead of evenly convex, and in having the ornamentation different from M'Coy's figure ; I have not, however, been able to discern the lines represented by him on his type.

Dimensions.—The holotype, the only specimen known to me, is at Edinburgh, in Mrs. Gray's collection. It is an external mould : therefore the figure is drawn from a wax-impression, which measures 19·5 millimetres in length and 5·75 mm. in width.

Locality and horizon.—Mullock Hill (Ayrshire), in rocks of Lower Llandovery age (Lapworth).

Loxonema reedi, sp. nov. (Pl. XI, figs. 4 *a* & 4 *b*.)

? *Loxonema striatissimum* (Salter MS.), Huxley & Etheridge, 1865, Catal. Coll. Foss. Mus. Pract. Geol. p. 12.

? *Murchisonia striatissima* (Salter MS.), 1878, Catal. Cambr. & Sil. Foss. Mus. Pract. Geol. p. 55.

Non *Loxonema striatissimum*, F. R. Cowper Reed, 1897, 'The Fauna of the Keisley Limestone' pt. ii, Quart. Journ. Geol. Soc. vol. liii, p. 78 & pl. vi, fig. 6.

Diagnosis.—Shell small, conical, composed of about fourteen whorls. Whorls increasing gradually, smooth, adpressed at the

[1] 'Fragmenta Silurica' 1880, p. 14 & pl. xv, fig. 19. (This figure shows no lines of growth.)

[2] 'Brit. Pal. Foss.' 1855, p. 304 & pl. i L, fig. 17.

suture, concave below that and then convex. Sutures very slightly inclined. Lines of growth strong, curving very obliquely backward above and less strongly forward below; sinus situated above the middle of the whorl.

Remarks and resemblances.—Two shells now registered as Nos. 21061 & 21062, in the Museum of Practical Geology, representing distinct species, are placed together on the same tablet with the name *Loxonema striatissimum*. The name was probably given by Salter in MS., and was published by Huxley & Etheridge in 1865.[1] Later the genus was changed to *Murchisonia*, and the specimens were entered as *M. striatissima* in the Catal. Cambr. & Sil. Foss. Mus. Pract. Geol. 1878, p. 55. No descriptions were given at either of these dates. In 1897 Mr. F. R. Cowper Reed[2] described a species under the name of *L. striatissimum*, considering it conspecific with one of these specimens in the Museum of Practical Geology, but he did not state which. Through his courtesy I have been enabled to examine his holotype. It appears to me quite distinct from either: it is much larger, and the contour is different. As, however, it is merely (with the exception of a small portion of the base) an internal mould, it is impossible to make an accurate comparison. Considering the above circumstances, it seems advisable to drop the name *striatissima* for the shells numbered 21061 & 21062 respectively, and to consider each a new species. I suggest calling the former *Loxonema reedi* and regard it as the holotype. There is no doubt as to its being *Loxonema* and not *Murchisonia*, as the characteristic form and lines of growth are well preserved. A fragment consisting of about two and a half whorls from the same locality (namely, the Chair of Kildare), in the Sedgwick Museum, may be this species; but it is larger, slightly compressed obliquely, and the surface is worn: it cannot, therefore, be identified with certainty. *L. reedi* somewhat resembles *L. ledburiense* (p. 219) in being much elongated, and in the high position of the sinus; but it is much smaller, the whorls are more excavated above, and the obliquity of the lines of growth is not so great, more especially below. In its small size, it is like *L. dalecarlicum*, Lindstr.; but it is distinguished therefrom by having the whorls concave above instead of evenly convex.

Dimensions.—The length of the holotype is 21 millimetres. The specimen is so much embedded in the matrix that it is impossible to ascertain its exact width.

Locality and horizon.—Chair of Kildare, in rocks of Upper Bala age (Cowper Reed).

Subgenus Rhabdostropha, Donald.

Rhabdostropha, Donald, 1905, Quart. Journ. Geol. Soc. vol. lxi, pp. 564–65.

Diagnosis.—Shell much elongated, composed of numerous,

[1] Catal. Coll. Foss. Mus. Pract. Geol. p. 12.
[2] Quart. Journ. Geol. Soc. vol. liii, p. 78 & pl. vi, fig. 6.

convex whorls. Ornamented by spiral lines, two or three of which frequently give the appearance of a sinual band.

Genotype.—*Rhabdostropha grindrodi*, Donald.

Remarks and resemblances.—This subgenus agrees with *Loxonema* sensu stricto in general form, but is distinguished in being ornamented by spiral lines of irregular strength, two or three of which are frequently more prominent than the others and give the impression of a sinual band. This causes a superficial resemblance to *Hormotoma* (to which subgenus a specimen of the species *Rh. pseudofasciata* was erroneously referred by Salter); the lines of growth, however, pass over the band without a break, and do not make a tongue-shaped sinus. In ornamentation this subgenus resembles *Aclisina*; but it is of greater proportions, and the structure is different.

Range.—As far as at present known, from the Wenlock to the Lower Ludlow.

RHABDOSTROPHA GRINDRODI, Don.

For description and figure of holotype, see Quart. Journ. Geol. Soc. vol. lxi (1905) p. 565 & pl. xxxvii, fig. 1.

Remarks.—Since writing that description I have met with another specimen, which is in the Oxford University Museum. It consists of about five and a half whorls and is in fairly good preservation, showing the lines of growth.

Dimensions.—Its length is 34 millimetres; the width is 15 mm.

Locality and Horizon.—This specimen occurred at Ledbury, in the Lower Ludlow.

RHABDOSTROPHA PSEUDOFASCIATA, Don. (Pl. XI, fig. 6.)

For description and figure of holotype, see Quart. Journ. Geol. Soc. vol. lxi (1905) p. 566 & pl. xxxvii, fig. 2.

Remarks.—In the Oxford University Museum there is also a specimen of this species. It is embedded in the matrix, and only four whorls are exposed; these show the lines of growth and some of the spiral striæ. Sir Charles Holcroft has a small example, which seems to bear the characteristics of this species. It is remarkable for being very slightly crushed and for possessing ten whorls, a greater number than I have seen preserved in any other specimen. The lines of growth and traces of spiral lines are visible on the penultimate and body-whorls. Besides this, he has five specimens which probably belong here: they are internal moulds, and only two show traces of the lines of growth.

Dimensions.—The length of the Oxford shell =57 millimetres and the width = about 26 mm. Sir Charles Holcroft's best preserved example (Pl. XI, fig. 6) is 34 millimetres in length and 13 mm. in width. The largest of the internal moulds consists of about six whorls, the length of which is 62 mm. and the width about 24 mm. The other moulds have only five whorls, and are slightly smaller.

Locality and horizon.—The specimen in the Oxford University Museum occurred at Ledbury, in the Lower Ludlow. The others come from the Wenlock Shale of Dudley. The holotype is from the Wenlock Limestone.

RHABDOSTROPHA STOKEI, sp. nov. (Pl. XI, fig. 7.)

Diagnosis.—Shell composed of numerous whorls. Whorls flattened below the suture, then convex, smooth. An obscure band is situated on the body-whorl about two-thirds of the height from the base, limited above by a strong thread; and there is another strong thread immediately below the suture. Suture apparently greatly inclined. Lines of growth strong, curving very obliquely backward above, forming a shallow sinus, and then advancing with but a slight degree of obliquity.

Remarks and resemblances.—I am acquainted with only one specimen of this species, which is in the Lightbody Collection, Manchester Museum; it is a mere fragment, consisting of the body-whorl and a portion of the penultimate, which are crushed and embedded in the matrix. The lines of growth are very distinct on the body-whorl, and may be clearly traced passing over the band: only forming a shallow, and not a deep tongue-shaped sinus, as in *Hormotoma*, Salter, and *Sinuspira*, Perner. I therefore place it in the subgenus *Rhabdostropha* with *Rh. grindrodi* and *Rh. pseudofasciata*. It greatly resembles the latter, but may be distinguished by its smaller size, and probably more slender form; by having a strong thread at the suture; and by the lines of growth curving backwards more obliquely above. It differs from the former by the last-named characteristic, as well as by the higher and less convex whorls. It is, however, difficult to make a just comparison, owing to the specimen being fragmentary and crushed.

Dimensions.—The length of the fragment, consisting of two whorls, is 22 millimetres, the width being 12 mm.

Locality and horizon.—Under Stoke Wood, in the Lower Ludlow.

Subgenus STYLONEMA, Perner, emend.

Stylonema, J. Perner, 1907, 'Syst. Sil. Centre Bohême' pt. i, vol. iv, Gastéropodes, tome ii, p. 325.

Diagnosis.—Shell greatly elongated, turriculated, nearly cylindrical, composed of numerous whorls. Whorls convex, low. Sutures but little inclined. Lines of growth slightly sinuated.

Genotype.—*Loxonema potens*, Barr.

Remarks and resemblances.—This subgenus was formed by Dr. Perner, for shells differing from *Loxonema* sensu stricto in being as a rule of greater size, in having broader whorls, nearly horizontal sutures, and less sinuated lines of growth. He mentions, however, that some species appear to be intermediate, having the strongly sinuated lines of growth of *Loxonema* s. str., while bearing the other characteristics of *Stylonema*; others again have the general form of *Loxonema* s. str., but at the same time they possess the slightly curved lines of growth of *Stylonema*.

Stylonema (?) hibernicum, sp. nov. (Pl. XI, fig. 8.)

Diagnosis.—Shell small, conical, composed of more than six whorls. Whorls smooth, flattened above, convex below, adpressed at the suture. Lines of growth very fine, slightly curved. Sutures rather oblique. Aperture unknown.

Remarks and resemblances.—The holotype, which is the only specimen known to me, is in the Museum of Practical Geology; its registered number is 21062, and it is associated with the specimen described as *Loxonema reedi*. The finer and less sinuated lines of growth, however, distinguish it from that species; also there are traces of a faint impressed submedian spiral line on the penultimate and body-whorls. The lines of growth are much less strongly curved than in the typical *Loxonema*: therefore I place it provisionally in the subgenus *Stylonema*, Perner, though it is of much smaller dimensions than is usual in that genus. It bears some resemblance to *Holopella*, M'Coy, but differs in having less convex whorls and adpressed sutures.

Dimensions.—The length of the holotype is 19 millimetres. The shell is too much embedded in the matrix to ascertain the width.

Locality and horizon.—Chair of Kildare, in limestone of Upper Bala age (Cowper Reed).

Stylonema (?) præteritum, sp. nov. (Pl. XI, fig. 9.)

Diagnosis.—Shell of medium size, conical, composed of about ten whorls. Whorls broad, flattened at the suture, concave above and very convex below. Sutures slightly inclined. Lines of growth extremely fine and close together, curving but little backward above and forward below. Base convex. Aperture unknown.

Remarks and resemblances.—I refer this species to the genus *Stylonema*, Perner, on account of the broad whorls, the small obliquity of the sutures, and the slightly sinuated lines of growth. I do so, however, with a query, for it bears considerable resemblance to some members of *Holopella*, M'Coy, which genus differs from *Loxonema* by having the aperture circular and entire. In the absence of any knowledge of the form of the aperture of either this or the last described species, we must remain in some uncertainty as to the genus in which they should be placed. *Stylonema (?) præteritum* is distinguished from *Holopella tenuicincta*, M'Coy, which occurs at the same locality, by having a greater spiral angle, less evenly convex whorls, and less oblique sutures. The whorls are rather lower, and not so much flattened above as those of *Stylonema (?) hibernicum*.

Dimensions.—Only one specimen is known to me. It is in Mrs. Gray's collection, at Edinburgh. It is an external mould, and therefore the drawing is made from a wax-impression. Length = 27 millimetres; width = 9·5 mm.

Locality and horizon.—Mullock Hill (Ayrshire), in rocks of Lower Llandovery age (Lapworth).

Genus Hormotoma, Salter.

Hormotoma inceptor, sp. nov. (Pl. XI, fig. 10.)

Diagnosis.—Shell very elongated, composed of more than eleven whorls: these are high, convex, and smooth. Lines of growth fine, slightly irregular in strength, arching obliquely backward above and still more obliquely forward below, forming a somewhat deep sinus situated rather above the middle of the body-whorl and slightly below the middle of the penultimate whorl. Band very faintly limited. Aperture unknown.

Remarks and resemblances.—The holotype (No. 22447), the only specimen known to me, is in the Museum of Practical Geology. It is very imperfectly preserved, and is so much embedded in the matrix that the earlier portion of the spire is but partly seen in section. The lines of growth are distinct on a portion of the body-whorl and the form and depth of the sinus are clearly indicated. The band, however, is not very distinct; there appears to be a faint groove above the sinus on the body-whorl, but it is not definitely limited below, and is barely discernible on the penultimate whorl.

It has most resemblance to *H. grayianum*, Don.;[1] but the band is situated higher, and does not appear to have had strong bordering lines. In the character of the lines of growth it is very like *Sinuspira tenera* (Barr.),[2] but although the band is indistinct, there is evidence of its having existed, and so I refer the species to the genus *Hormotoma*. This relationship appears all the more probable since *Sinuspira*, Perner (so far as I know) is only represented by one species which occurs in E–e 2 (Upper Silurian); whereas species of *Hormotoma* occur as early as the Cambrian.

Dimensions.—The length of the specimen figured (Pl. XI, fig. 10) is 39 millimetres, and the width as seen is 9 mm.; this may not represent the original dimensions, as the shell is crushed and broken.

Locality and horizon.—Builth Bridge, in the Llandeilo Flags.

The scarcity of material, which is widely scattered in many public and private collections, has necessitated my seeking assistance from numerous sources, and I desire to express my warmest thanks to all who have most graciously helped by the loan of specimens and in various other ways. In some instances the search for examples was vain; but the desire to aid was the same, and I am just as deeply grateful. Thus I have received kind assistance from Mrs. Robert Gray, Dr. A. Smith Woodward, Mr. R. B. Newton, Dr. Kitchin, Mr. H. A. Allen, Prof. Hughes, Mr. Cowper Reed, Prof. Sollas, Dr. Scharff, Dr. Lee and Mr. Macconochie of the Geological Survey of Scotland, Mr. H. J. Seymour of the Geological Survey of Ireland, Prof. Holm, Dr. Hoyle, the Rev. D. M. D. La Touche, Sir Charles Holcroft, Mr. Madeley, Mr. Edwards of the Worcester Museum, Mr. Linnæus Hope of the Carlisle Museum, Mr. Reynolds, and Mr. C. D. Sherborn.

[1] Quart. Journ. Geol. Soc. vol. lv (1899) p. 270 & pl. xxii, fig. 10.

[2] 'Syst. Sil. Centre Bohême' vol. iv, Gastéropodes, par J. Perner, tome ii (1907) pp. 131, 132, with text-figs. 177–79, & pl. xcix, figs. 41–44.

EXPLANATION OF PLATES X & XI.

Plate X.

Figs. 1 *a* & 1 *b*. *Loxonema sinuosum* (Sow.). Fig. 1 *a*. Type, × 2. Fig. 1 *b*. Portion of body-whorl, × 3. Garden House Quarry, Aymestry. Collection of the Geological Society of London.

2 *a* & 2 *b*. *Loxonema cornubicum*, sp. nov. (*L. sinuosum*, Phill.) Fig. 2 *a* × 1½. Fig. 2 *b*. Body-whorl showing aperture, × 1½. South Petherwin. Museum of Practical Geology, Jermyn Street, London.

Fig. 3. *Loxonema intumescens (?)*, Lindstr. × 2. Flattened by pressure. Ledbury Tunnel. Piper Collection, British Museum (Nat. Hist.).

Figs. 4 *a* & 4 *b*. *Loxonema latouchei*, sp. nov. Fig. 4 *a* × 1½. Collection of the Rev. W. M. D. La Touche. Fig. 4 *b*. Portion of the body-whorl of another specimen, showing the lines of growth, × 2. Watson Collection, Manchester Museum. Stoke Wood Quarry.

5 *a* & 5 *b*. *Loxonema ledburiense*, sp. nov. Fig. 5 *a* × 1½. Fig. 5 *b*. Portion of a whorl showing lines of growth, × 3. Ledbury. Oxford University Museum.

6 *a* & 6 *b*. *Loxonema planatum*, sp. nov. Fig. 6 *a* × 1½. Flattened by pressure. British Museum (Nat. Hist.). Fig. 6 *b*. Portion of two whorls of another specimen, showing the lines of growth, × 2. Oxford University Museum. Garcoed, Usk.

Plate XI.

Fig. 1. *Loxonema perneri*, sp. nov. ×1½. Flattened by pressure. Ludlow Museum of Practical Geology, Jermyn Street, London.

2. *Loxonema perneri*, var. *dudleyense*, nov. × 2. Ledbury Tunnel. Piper Collection, British Museum (Natural History).

3. *Loxonema perneri*, var. *dudleyense*. × 1½. Shell flattened by pressure Dudley. Museum of Practical Geology, Jermyn Street, London.

Figs. 4 *a* & 4 *b*. *Loxonema reedi*, sp. nov. Fig. 4 *a* × 3. Fig. 4 *b*. Portion of whorl enlarged to show lines of growth, × 4. Chair of Kildare. Museum of Practical Geology, Jermyn Street, London.

Fig. 5. *Loxonema grayianum*, sp. nov. × 2. Mullock Hill (Ayrshire). Mrs. Gray's collection, Edinburgh.

6. *Rhabdostropha pseudofasciata*, Don. × 1½. Dudley. Sir Charles Holcroft's collection.

7. *Rhabdostropha stokei*, sp. nov. × 1½. Under Stoke Wood. Lightbody Collection, Manchester Museum.

8. *Stylonema (?) hibernicum*, sp. nov. × 2. Chair of Kildare. Museum of Practical Geology, Jermyn Street.

9. *Stylonema (?) præteritum*, sp. nov. × 1½. Mullock Hill (Ayrshire). Mrs. Gray's collection, Edinburgh.

10. *Hormotoma inceptor*, sp. nov. × 1½. Builth Bridge. Museum of Practical Geology, Jermyn Street.

Discussion.

The President (Prof. Sollas) expressed his sense of the great amount of labour which had been expended in the investigation of this interesting genus. It was fortunate that the study of Palæozoic Gasteropods, which made great demands on the skill of the palæontologist, was in hands so competent as those of the Authoress.

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CONTENTS.

[No. 259 of the Quarterly Journal will be published next August.]

[The Editor of the Quarterly Journal is directed to make it known to the Public that the Authors alone are responsible for the facts and opinions contained in their respective Papers.]

*** The Council request that all communications intended for publication by the Society shall be clearly and legibly written on one side of the paper only, with proper references, and in all respects in fit condition for being at once placed in the Printer's hands. Unless this is done, it will be in the discretion of the Officers to return the communication to the Author for revision.

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Vol. LXV. Part 3. AUGUST 31st, 1909. **No. 259.**

C. A. White

THE

QUARTERLY JOURNAL

OF THE

GEOLOGICAL SOCIETY.

EDITED BY

THE ASSISTANT-SECRETARY.

[With Twelve Plates, illustrating Papers by Mr. H. H. Thomas, Mr. H. Dewey, Prof. W. M. Davis, Mr. A. M. Finlayson, and Mr. A. J. C. Molyneux.]

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EVENING MEETINGS OF THE GEOLOGICAL SOCIETY TO BE HELD AT BURLINGTON HOUSE.

Session 1909–1910.

1909.		
Wednesday,	November	3*—17*
„	December	1 —15*
1910.		
„	January	12*—26*
„	February (Anniversary, Friday, Feb. 18th)	9*—23*
„	March	9*—23
„	April	13*—27
„	May	11*—25
„	June	15*

[*Business will commence at Eight o'Clock precisely.*]

The dates marked with an asterisk are those on which the Council will meet.

The following specimens and maps were exhibited :—

Specimens illustrating the effects of pressure and crushing upon flint, exhibited by S. Hazzledine Warren, F.L.S., F.G.S.

Geological Survey of Ireland :—1-inch map, Drift-Series—Londonderry (parts of Sheets 11, 12, 17, & 18), 1908, presented by the Director of H.M. Geological Survey.

Geological map of the Northern portion of British Guiana, on the scale of 10 miles to the inch, by J. B. Harrison, H. I. Perkins, & C. W. Anderson, 1906, presented by the Authors.

Imperial Geological Survey of Japan, $\frac{1}{200,000}$ map, Zone 3, col. iii & Zone 13, col. ix, with the accompanying Explanations, presented by the Director of that Survey.

April 7th, 1909.

Prof. W. J. Sollas, LL.D., Sc.D., F.R.S., President, and afterwards H. W. Monckton, Treas.L.S., Vice-President, in the Chair.

Bernard Richard Lucas, Winnington Park, Northwich (Cheshire), was elected a Fellow of the Society.

The List of Donations to the Library was read.

The President announced that the Daniel-Pidgeon Fund for 1909 had been awarded to Alexander Moncrieff Finlayson, M.Sc., Assoc. Otago School of Mines, who proposes to undertake researches on the genesis of the sulphidic ores.

The following communications were read :—

1. 'On Overthrusts at Tintagel (North Cornwall).' By Henry Dewey, F.G.S. (Communicated by permission of the Director of H.M. Geological Survey.)

2. 'The Lahat "Pipe": A Description of a Tin-Ore Deposit in Perak (Federated Malay States).' By John Brooke Scrivenor, M.A., F.G.S., Geologist to the Federated Malay States Government.

3. 'On the Sculptures of the Chalk Downs in Kent, Surrey, and Sussex.' By George Clinch, F.G.S., F.S.A.Scot.

The following specimens and lantern-slides were exhibited :—

A series of specimens from the Tintagel District of Cornwall and lantern-slides, exhibited by H. Dewey, F.G.S., in illustration of his paper.

Lantern-slides, exhibited by G. Clinch, F.G.S., F.S.A.Scot., in illustration of his paper.

Specimen of a [?] water-stone or enhydro, from the West Indies, exhibited by C. Carus-Wilson, F.R.S.E., F.G.S.

April 28th, 1909.

Prof. W. J. Sollas, LL.D., Sc.D., F.R.S., President, and afterwards Prof. W. W. Watts, Sc.D., F.R.S., Vice-President, in the Chair.

The List of Donations to the Library was read.

The following communications were read :—

1. 'The Boulders of the Cambridge Drift.' By Robert Heron Rastall, M.A., F.G.S., and James Romanes, B.A.

2. 'The Nephrite and Magnesian Rocks of the South Island of New Zealand.' By Alexander Moncrieff Finlayson, M.Sc., A.O.S.M. (Communicated by Prof. W. W. Watts, Sc.D., F.R.S., V.P.G.S.)

The following specimens, lantern-slides, and maps were exhibited :—

Specimens of boulders, rock-sections, and lantern-slides, exhibited by R. H. Rastall, M.A., F.G.S., and J. Romanes, B.A., in illustration of their paper.

Rock-specimens and lantern-slides, exhibited in illustration of the paper by A. M. Finlayson, M.Sc., A.O.S.M.

Sheets 33 & 41 of the Geological Map of Cape Colony, presented by the Geological Commission of that Colony.

May 12th, 1909.

Prof. W. J. Sollas, LL.D., Sc.D., F.R.S., President, and afterwards Dr. J. J. H. Teall, M.A., F.R.S., Vice-President, in the Chair.

George Augustus Burton, Highfield, Nunthorpe R.S.O. (Yorkshire); Joseph James Burton, M.I.M.E., Rosecroft, Nunthorpe R.S.O. (Yorkshire); Richard Cardiff, The Drive, Fulham Road, S.W.; George MacDonald Davies, 17 Elmwood Road, Croydon; Cyril S. Fox, Virginia House, Woodbury Salterton, near Exeter;

Alexander Macmillan Heron, Geological Survey of India, Calcutta; Arthur John Martin, M.Inst.C.E., 6 Denbigh Gardens, Richmond (Surrey); and Carl Robert Sticht, Mount Lyell Mines, Queenstown (Tasmania), were elected Fellows of the Society; Dr. Feodor Černyšev, St. Petersburg, and Prof. René Zeiller, Paris, were elected Foreign Members of the Society; and Dr. Daniel de Cortázar, Madrid; Prof. Maurice Lugeon, Lausanne; and Prof. Ralph S. Tarr, Ithaca (New York), were elected Foreign Correspondents of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. 'The Hartfell-Valentian Succession around Plynlimon and Pont Erwyd (North Cardiganshire).' By Owen Thomas Jones, M.A., B.Sc., F.G.S.

2. 'The Geology of the Neighbourhood of Seaford (Sussex).' By James Vincent Elsden, B.Sc., F.G.S.

The following specimens and lantern-slides were exhibited:—

Rock-specimens from near Plynlimon and Pont Erwyd, and lantern-slides, exhibited by O. T. Jones, M.A., B.Sc., F.G.S., in illustration of his paper.

A model of the neighbourhood of Seaford (Sussex), geologically coloured, a series of fossils from the Chalk, and lantern-slides, exhibited by J. V. Elsden, B.Sc., F.G.S., in illustration of his paper.

May 26th, 1909.

Prof. W. J. Sollas, LL.D., Sc.D., F.R.S., President, in the Chair.

The List of Donations to the Library was read.

The Names of certain Fellows of the Society were read out for the first time, in conformity with the Bye-Laws, Sect. VI, Art. 5, in consequence of the Non-Payment of the Arrears of their Contributions.

The following communications were read:—

1. 'The Cauldron-Subsidence of Glen Coe and the Associated Igneous Phenomena.' By Charles Thomas Clough, M.A., F.G.S., Herbert Brantwood Muff, B.A., F.G.S., and Edward Battersby Bailey, B.A., F.G.S. (Communicated by permission of the Director of H.M. Geological Survey.)

2. 'The Pitting of Flint-Surfaces.' By Cecil Carus-Wilson, F.R.S.E., F.G.S.

The following specimens, maps, etc. were exhibited :—

Rock-specimens, photographs, lantern-slides, and microscopic rock-sections, exhibited by C. T. Clough, M.A., F.G.S., H. B. Muff, B.A., F.G.S., and E. B. Bailey, B.A., F.G.S., in illustration of their paper.

Flints illustrating pitting, exhibited by C. Carus-Wilson, F.R.S.E., F.G.S., in illustration of his paper.

Twenty-six 6-inch Geological Survey Maps of South Wales, presented by the Director of H.M. Geological Survey.

June 16th, 1909.

Prof. W. J. Sollas, LL.D., Sc.D., F.R.S., President, in the Chair.

John Leyborne Popham, P.O. Box 669, Bulawayo (Rhodesia); Daniel J. Rees, Derwenlas, Neath (Glamorgan); and James Stewart Whitehouse, Warnham (Sussex), were elected Fellows of the Society.

The Names of certain Fellows of the Society were read out for the second time, in conformity with the Bye-Laws, Sect. VI, Art. 5, in consequence of the Non-Payment of the Arrears of their Contributions.

The List of Donations to the Library was read.

The following communications were read :—

1. 'The Carboniferous Limestone of County Clare.' By James Archibald Douglas, M.A., B.Sc., F.G.S.

2. 'The Howgill Fells and their Topography.' By John Edward Marr, Sc.D., F.R.S., F.G.S., and George William Fearnsides, M.A., F.G.S.

3. 'On a New Species of *Sthenurus*.' By Ludwig Glauert, F.G.S.

4. 'On some Reptilian Remains from the Trias of Lossiemouth (Elgin).' By D. M. S. Watson, B.Sc. (Communicated by Prof. W. Boyd Dawkins, D.Sc., F.R.S., F.S.A., F.G.S.)

5. 'On some Reptilian Tracks from the Trias of Runcorn (Cheshire). By D. M. S. Watson, B.Sc. (Communicated by Prof. W. Boyd Dawkins, D.Sc., F.R.S., F.S.A., F.G.S.)

6. 'The Anatomy of *Lepidophloios laricinus*, Sternb.' By D. M. S. Watson, B.Sc. (Communicated by Prof. W. Boyd Dawkins, D.Sc., F.R.S., F.S.A., F.G.S.)

Dr. G. F. Herbert Smith, M.A., F.G.S., exhibited two forms of refractometer. The one (which reads directly to the second, and by estimation to the third, place of decimals) has a range extending from 1·300 to 1·795, and is intended for all translucent substances, especially minerals. The other (which reads directly to the third, and by estimation to the fourth, place of decimals) has a range extending from 1·3200 to 1·4200, and is intended for use with water and solutions in water, especially brines, for which reason it may be called a salinometer. The liquid film is illuminated from above, and the optical arrangements are such that the critical edge is blue, if coloured at all, in white light. Since the refractive indices of liquids change rapidly with the temperature, a water-jacket is provided for controlling the temperature of the observation; a thermometer, reading to degrees centigrade, is attached, underneath the instrument. The glass prisms are removable for cleaning purposes.

In addition to the exhibit just described, the following specimens, maps, etc. were exhibited :—

Specimens of Carboniferous Limestone from County Clare, thin sections of corals, and lantern-slides, exhibited by J. A. Douglas, M.A., B.Sc., F.G.S., in illustration of his paper.

Five sheets of the 6-inch Geological Survey Map of Scotland, presented by the Director of H.M. Geological Survey.

Map of the Coalfields of the United States, by M. R. Campbell, 1908, presented by the Director of the U.S. Geological Survey.

15. *A* Contribution *to the* Petrography *of the* New Red Sandstone *in the* West *of* England. By Herbert Henry Thomas, M.A., B.Sc., F.G.S. (Read March 10th, 1909.)

[Plate XII.]

Contents.

I. Introduction.

In a former paper [1] communicated to this Society I dealt with the mineralogical constitution of the great Pebble-Bed, as developed in Devon and Somerset. The results obtained encouraged me to undertake a similar study of the other members of the New Red Sandstone Series in that district; and, in the following communication, I have endeavoured to point out the mineralogical and physical differences exhibited by the microscopic particles which form the finer portions of the deposits. The classification and subdivision of the New Red Sandstone Series in Devon and Somerset has gradually evolved from the labours of several geologists, and I propose to use those subdivisions which are now adopted by the Geological Survey.[2]

The New Red Sandstone in the area under consideration may be divided as follows, commencing with the older beds:—

(1) Lower Breccias and Lower Sandstones.
(2) Lower Marls.
(3) Pebble-Bed and Conglomerate.
(4) Upper Sandstones and Marls, with the Upper Keuper Sandstones of the Bridgwater district.

These subdivisions are founded solely on lithological characters, and therefore form the most natural basis for a petrographical study.

The Lower Breccias are well-developed, and have been examined on the south coast at Teignmouth and Dawlish, along the western side of the Exe estuary on the flanks of the Haldon Hills, in the Exeter district, and in the Crediton and Stogumber valleys. They usually consist of deep-red breccias, sands, and sandstones, most

[1] 'Mineralogical Constitution of the Finer Material of the Bunter Pebble-Bed in the West of England' Quart. Journ. Geol. Soc. vol. lviii (1902) p. 620.

[2] W. A. E. Ussher, 'Geology of the Country around Exeter' Mem. Geol. Surv. 1902; see also 'Subdivisions of the Triassic Rocks, between the Coast of West Somerset & the South Coast of Devon' Geol. Mag. dec. 2, vol. ii (1875) p. 163.

often loose and incoherent, but occasionally compacted into rocks of more solid character.

The Lower Sandstones, which for the most part occupy a position above the breccias, have been studied on each side of the Exe estuary, in the vale of the Clyst, in the neighbourhood of Killerton and Brampford Speke, and in the Bridgwater area. They present many points of similarity to the sands and sandstones interbedded with the lower breccias.

The Lower Marls, consisting of red marls with sandstone-courses, the Pebble-Bed, and the Upper Marls and Sandstones have been dealt with from numerous localities in the two counties.

At first I confined my attention to that part of the country which lies between Wiveliscombe on the north, and the south coast of Devon; but later, at the instigation of Mr. Ussher, I extended the work so as to include the red rocks lying to the west and east of the Quantock inlier, in the districts of Taunton and Bridgwater.[1]

Nearly one hundred samples were collected from various localities and horizons, each sample receiving the following treatment:—The sand or crushed sandstone was first put through a fairly fine sieve, so as to separate out the larger rock-fragments and leave, as far as possible, simple mineral grains. The coating of iron-oxides was then removed from the grains forming the finer portion, which, after washing and drying, was subjected to two fractional separations by means of Thoulet's solution.[2] Three residues were thus prepared from each sample, of which portions were mounted for microscopical study. One residue contained all those minerals present in the sample which had a specific gravity greater than 2·8, the other two respectively contained the bulk of the quartzose and of the felspathic material. The heaviest residue is in general a very small percentage of the whole sample, but at the same time the ratio of the lightest part to the heavier varies considerably in all divisions of the New Red Sandstone.

In some respects, the treatment of sands and sandstones with hydrochloric acid is disadvantageous: for, while the iron-oxide, which coats the grains, is removed, it is probable that some of the less stable minerals are attacked and even eliminated. If, however, after such treatment mineralogical differences can be detected in the residues from various samples, such distinctions are obviously the most reliable: for, if our considerations extended to minerals easily attacked by acids, we should then deal with minerals which might be removed locally from the deposit by natural chemical agencies, and this would give misleading ideas as to their distribution.

[1] 'Geology of the Quantock Hills, &c.' Mem. Geol. Surv. 1908, pp. 60–64.

[2] A solution of the double iodide of mercury and potassium in water. Although it has a great drawback in its poisonous nature, I have found it by far the cleanest to handle and the easiest of recovery. It has many advantages over other heavy liquids; it is less viscous than a solution of cadmium-borotungstate of the same density, and is not so prone to develop convection-currents with slight changes of temperature as in the case of the more mobile organic fluids (bromoform, etc.).

II. The Minerals of the New Red Sandstone.

The following is a list of the constituents, hitherto identified, forming the finer material of the New Red Sandstone; the minerals are arranged according to their crystallographic systems:—

(i) *Cubic.*
- Fluorspar.
- Garnet.
- Magnetite.

(ii) *Tetragonal.*
- Anatase.
- Cassiterite (?).
- Rutile.
- Zircon.

(iii) *Rhombohedral.*
- Apatite.
- Calcite.
- Ilmenite.
- Hæmatite.
- Quartz.
- Tourmaline.

(iv) *Orthorhombic.*
- Barytes.
- Brookite.
- Celestine.
- Cordierite (?).
- Sillimanite.
- Staurolite.
- Topaz.

(v) *Monoclinic.*
- Actinolite.
- Biotite.
- Chlorite.
- Muscovite.
- Orthoclase.
- Sphene.

(vi) *Triclinic.*
- Cyanite.
- Microcline.
- Plagioclase-felspars.

In addition to the simple mineral-grains, compound grains and mineral-aggregates are common, including leucoxene, perthitic intergrowths of felspar, serpentine, and micaceous decomposition-products (presumably after some aluminous silicate, such as cordierite, andalusite, or cyanite); grains of chert, felsite, micro-pegmatite, and mica-schist are of frequent occurrence.

Among the minerals acting as cements may be mentioned calcite, limonite, hæmatite, barytes, celestine, and gypsum.

It will be seen, on comparing the foregoing list with that given in my previous paper, that the mineral species present in the New Red Sandstone as a whole are, with a few exceptions, those already noted from the Pebble-Bed. In the following description of certain mineral species it is intended only to supplement the descriptions already given.

Those minerals which are now mentioned as occurring in New Red sediments for the first time, or appear to call for treatment in somewhat greater detail, are—anatase, calcite, hæmatite, quartz, tourmaline, barytes and celestine, cordierite (?), staurolite, topaz, actinolite, chlorite, and selenite.

Anatase.—This mineral occurs in two distinct habits: (*a*) tabular and (*b*) pyramidal.

(*a*) The tabular variety consists usually of colourless or sometimes pale-yellow crystals, rarely exceeding 0·1 mm. in greatest width. The basal plane (001) is large, and the pyramid-planes {111} exceedingly narrow. The crystals are either single and well formed, or are seen to consist of several crystals in parallel

intergrowth as figured by Thürach,[1] Cayeux,[2] and others (Pl. XII, fig. 1, *a* & *c*). Occasionally, the basal plane is absent, and its place is taken by low pyramids of some form such as {h h l}, as in the specimen from the Lower Breccias of the Ness at Teignmouth (Pl. XII, fig. 1 *b*).

(*b*) The pyramidal variety occurs in steel-blue or yellow crystals with the basal plane small or absent, and having well-developed pyramid-planes modified only by narrow prisms {110}. The pyramid-planes are deeply striated parallel to their intersection with the prism (Pl. XII, figs. 3 & 5). These forms are accurately described by Thürach, who, in addition, mentions microscopic anatase with a pyramid of the second order {h o l} and a double pyramid {h k l}. These I have not noticed on any crystals from the New Red rocks.

Anatase belongs essentially to the crystalline metamorphic rocks; but it may be formed from a variety of titaniferous minerals on their decomposition, as, for instance, from ilmenite, sphene, etc.[3] Mr. J. B. Scrivenor described the alteration of ilmenite into anatase (Pl. XII, fig. 7) in the Triassic sandstones of Cheshire,[4] and stated that in his opinion the change had taken place since the deposition of the sandstone. In the south-western area I have observed many crystals of anatase attached to ilmenite or leucoxene; and there is little doubt, from the sharpness of the angles and the general fragility of the crystal-groups, that nearly all the tabular anatase has been formed as Mr. Scrivenor suggested.

Some of the pyramidal and more acute forms, however, show unmistakable signs of wear; their edges are rounded, and the crystals themselves far from perfect. These most certainly have been derived from pre-existing rocks.

Calcite.—Calcite enters into the composition of most of the New Red rocks in the neighbourhood of calcareous inliers of older rocks, and in some divisions of the Red rocks far removed from such calcareous masses. It occurs chiefly as a calcareous cement, but most probably also as detritus. Some of the upper marls are remarkable for their high percentages of calcium-carbonate when quite remote from any older calcareous rocks.

Hæmatite.—This mineral also occurs as a cement, and is often associated with secondary growths of quartz. It exists as thin plates coloured a deep red; also as minute botryoidal grains, made up of spheroidal masses with radiate structure which give a black cross between crossed nicols. It is evidently of secondary origin.

[1] 'Ueber das Vorkommen mikroskopischer Zirkone & Titan-Mineralien in den Gesteinen' Würzburg, 1884.

[2] Mém. Soc. Géol. du Nord, vol. iv, no. 2 (1897) pl. x.

[3] A. Lacroix, 'Sur qq. Cas de Production d'Anatase par Voie Secondaire' Bull. Soc. Franç. Min. vol. xxiv (1901) p. 425. See also W. Prinz, 'Les Oxydes de Titane . . . . de qq. Roches du Brabant' Bull. Soc. belge Géol. vol. xxi (1907) Mém. p. 383.

[4] Min. Mag. vol. xiii (1903) p. 348.

Quartz.—Quartz, which generally forms more than 50 per cent. of the New Red sands, may, for purposes of description, be divided into primary and secondary.

The detrital or primary quartz may be further divided, according to whether it gives a uniform or an undulose extinction; and, following Dr. W. Mackie,[1] may be subdivided according to the nature of its inclusions, the inclusions being the best guide to the character of the rock from which the quartz was derived.

The subdivisions of the detrital quartz are as follows:—

(a) Quartz with included minerals presenting a regular outline, such as apatite, stumpy crystals of tourmaline, etc.

(b) With acicular inclusions, such as hair-like rutile, fibrous sillimanite, and needles of blue tourmaline.

(c) With irregular inclusions, such as patches of brown glass, small masses of felsitic matter, fluid, and gas.

Secondary quartz is not of common occurrence in the New Red sands of the West of England. It was stated by the Rev. A. Irving[2] that the angularity of the grains forming the sands and sandstones of the great Pebble-Bed seemed to be largely due to the deposition of secondary quartz; but, although a thin coating of this material is occasionally met with, it cannot in any sense be regarded as a general feature. It rarely acts as a cement, but tends to produce doubly terminated pyramidal crystals with a quartz-grain as a nucleus.

Tourmaline.—This mineral is present in the heavy residues from sedimentary rocks of all ages, but in the New Red rocks it occurs in three distinct varieties. The most common variety is, generally speaking, of a deep-brown colour, and exists either as short stumpy prisms terminated by the simple rhombohedron, or as rounded to spherical grains.

A light-blue variety occurs plentifully in some of these rocks, occasionally in greater abundance than the deeper coloured type mentioned above. It is nearly always acicular, and slender crystals are often grouped together in roughly radiating bundles. The needles show little or no sign of terminal planes, and the groups occur either free, or embedded in quartz after the manner of luxullianite. The point to which the individual rays of a group converge is often of a brown colour.

The third variety is evidently connected chemically with the above-mentioned blue acicular crystals, but differs in its habit. It occurs as pale to deep blue, thin hexagonal plates (Pl. XII, fig. 6) flattened parallel to the base $\{111\}$. The rhombohedra are represented by narrow planes truncating the horizontal edges. The crystals occasionally show a zonal structure in various shades of blue, and always the emergence of an optic axis.

The basal plane $\{111\}$ is one not usually met with on tourmaline-crystals, and it seems unlikely that it would be so largely developed

[1] 'Sands & Sandstones of Eastern Moray' Trans. Geol. Soc. Edin. vol. vii (1893-99) pp. 148-72; see also H. C. Sorby, Quart. Journ. Geol. Soc. vol. xxxvi (1880) Proc. p. 46, and Monthly Microscop. Journ. vol. xviii (1877) p. 209; also J. A. Phillips, Quart. Journ. Geol. Soc. vol. xxxvii (1881) p. 6.

[2] Quart. Journ. Geol. Soc. vol. xlviii (1892) p. 71.

as to form crystals of this shape. It is probable, therefore, that in these crystals the true basal plane is not present, but that some external factor has determined a tabular habit. In all probability, these crystals were formed between the cleavage-planes of mica, and thus had their dimensions restricted in the direction of the vertical axis.

It appears that flaky crystals giving an interference-figure were detected by Mr. T. H. Cope[1] in the titaniferous iron-sands of Porth-Dinlleyn, on the coast of Carnarvonshire.

Barytes and celestine.—Both these minerals, more especially barytes, are met with as cementing materials, but (so far as can be judged) never as detritus. Many of the sandstones and marls, when broken up and separated by heavy solutions, give a large residue. The barytes under the microscope consists, as might be expected, of small rectangular grains bounded by the two good cleavages $\{001\}$ and $\{110\}$. It is associated with celestine, but the two minerals are indistinguishable in microscopic grains. They are easily identified, however, by their respective flame-tests; and, when occurring together, the presence of both is easily demonstrated by spectroscopic methods.

Celestine has been recorded from the Upper Marls of Peake and Salcombe Hills, near Sidmouth, by Mr. S. G. Perceval.

Cordierite (?).—Only one grain which might possibly be referred to unaltered cordierite has been met with, and that from the Lower Sandstone of East Town, east of Totland, in the Quantock region. It occurred as a somewhat rounded grain, with traces of a moderately good cleavage. It gave straight extinction, and showed feeble pleochroism from pale blue-grey to an indistinct shade of yellow. It contained a large number of minute opaque inclusions, probably iron-ores. No pleochroic halos were noticed. If this mineral is really cordierite, its occurrence is most unexpected; for, in rocks of this character, it would probably occur altered to pinite, or some other decomposition-product.

Staurolite.—On some horizons this mineral forms quite a considerable portion of the heavy residues, and is one of the most abundant heavy minerals. It occurs most often, in these rocks, in angular and rough grains of a pale-yellow to amber colour, measuring up to 0·5 mm. in greatest length. The angularity (Pl. XII, fig. 4 *c*) is due to the fraying-out of the mineral along the prism-cleavages parallel to the form $\{110\}$. The cleavage parallel to the form $\{010\}$ is also a prominent boundary-plane.

Very rarely it occurs in well-formed crystals. In the New Red rocks such good crystals as those figured in Pl. XII (figs. 4 *a* & 4 *b*) have not been met with. For descriptive purposes, therefore, I have shown two almost perfect crystals from more recent sediments, one from the Pliocene of Lenham, and the other from the blown sand of Newgale in Pembrokeshire. These crystals are tabular parallel to

[1] Proc. Liverp. Geol. Soc. vol. ix, pt. ii (1901–1902) p. 212.

the cleavage $\{010\}$. The long edges are modified by the prisms $\{110\}$, and the crystals are terminated by the forms $\{101\}$ and $\{001\}$. The large flat face (010) is normal to the obtuse bisectrix ($\mathfrak{a}$), and the axis of elongation ($=\mathfrak{c}$) lies in the plane of the optic axes. The pleochroic scheme for these crystals is

$\mathfrak{a}$ = pale straw-yellow ; $\mathfrak{b}$ = deep yellow.

Angular grains similar to those usually occurring in the Red rocks have been noted by many authors from a variety of sediments, including Cayeux from the Chalk, René Bréon from the marine and dune-sands of Britanny, Retgers from the dune-sands of Holland, Thürach from the sands of the Sahara, and Artini [1] from the alluvium of the North Italian rivers.

Topaz.—Topaz occurs sparingly as angular cleavage-fragments in the Lower Breccias and at some localities in the Pebble-Bed. The flakes are colourless, and give an interference-figure in convergent light showing an angle between the optic axes, in air, of about 110°. Usually, they are only thick enough to show the colours of the first order, and are full of gaseous and fluid inclusions.

Actinolite.—This mineral has been met with as pale-green acicular and fibrous aggregates, usually associated with pink garnet. The pleochroism is distinct, the greater absorption occurring in a plane at right angles to the axis of elongation of the needles. It presents the usual characters of actinolite from metamorphic rocks, and is the only amphibole that is known to occur in the Red rocks of this district.

III. Physical Characteristics of the Finer Material.

The grains forming the matrix of the Lower Breccias are invariably angular or but slightly rounded, thus presenting features almost identical with those of the larger rock-fragments with which they are associated. In the intercalated beds of sand and sandstone, however, a great difference in the grain is apparent. The particles forming these finer deposits are always well worn, and usually more so than those of the ordinary marine sands or dune-sands of coastal regions. In fact, many samples approximate very closely to the 'millet-seed' sands of deserts. This feature in connexion with British red sandstones has been pointed out by Phillips, Goodchild, and others. Sands of this type occur at Berry Head,[2] the western

[1] Riv. di Min. & Crist. Ital. vol. xix (1898) p. 33. Speaking (*ibid.* p. 41) of the staurolite from the River Adige, he says that it is 'Piuttosto abbondante, quasi sempre in granuli irregolari, a spigoli vivi; scarse inclusioni, colore vivace, pleocroismo distinto.'

[2] The rock at Berry Head occupies a fissure in the older rocks, and forms a pipe or dyke of fairly compact sandstone. The cementing-material is partly ferruginous and partly siliceous. Similar dykes have been noted in other districts (W. Pengelly, Trans. Devon. Assoc. vol. i, 1864, p. 40; also E. B. Tawney, Proc. Bristol Nat. Soc. n. s. vol. i, pt. ii, 1875, p. 162). In my former paper in this Journal I erroneously regarded the Berry Head rock as a possible outlier of Pebble-Bed; but, as pointed out by Pengelly and impressed upon me by Mr. Ussher, it must belong to an earlier, if not the earliest, period of the New Red Sandstone.

extremity of Torbay, and associated with the breccias of Dawlish and Heavitree (near Exeter).

The cementing-material in the Lower Breccias is almost always of a ferruginous nature, only becoming calcareous in the neighbourhood of limestone-masses of Devonian or Carboniferous age. A complete silica-cement never occurs; but secondary growths of silica have been noted in a few cases (as, for instance, Berry Head). Lithologically, the Lower Sandstones are similar to the beds of sand and sandstone associated with the Lower Breccias, and the same remark applies to the cementing materials.

The particles are all well rounded; but the rounding is most complete in the centre and south of Devon, especially in the Broad-Clyst district. Around the Somerset inliers of older rocks the rounding is not so well marked.

The grains forming the marls below the Pebble-Bed, owing to their extremely small dimensions, cannot readily be compared with those of other New Red divisions. The material, as might be expected from the size of the particles, is all angular; but, when it becomes sufficiently coarse to form beds of sand or sandstone, the grains are rounded. Well-rounded sands occurring in the Lower Marl subdivision have been noticed at St. Mary's Clyst, Hulham (near Exmouth), and several other localities; but the rounding is never so complete as in the sands of the lower divisions, and approximates more to that observable in the grains forming the matrix of the Pebble-Bed.

The finer grains of the Pebble-Bed are remarkably constant in character: they are subrounded, after the manner of fluviatile or marine sands. The constituents of the matrix of the Upper Marls and Sandstones, and of the Upper Keuper Sandstones of the Bridgwater area, are all angular to subrounded, according to size. Generally speaking, the rounding of the grains is less marked in this division of the New Red than in the sands of any other division.

With regard to the cementing-materials in the Upper Marls and Sandstones, in addition to the usual ferruginous material we find that calcium-carbonate is almost universal, and that substances such as barytes and gypsum play an important part locally.

In the marls, often far removed from any limestone-outcrop, the percentage of carbonate is extremely high: for instance, four samples taken from the deep boring at Lyme Regis[1] yielded the following percentages of carbonate, estimated as $CaCO_3$:—

Depth of 437 feet	11·51
„ 850 „	16·49
„ 1200 „	21·10
„ 1300 „	12·26

Barytes was a prevalent constituent of a sample taken from a depth of 1000 feet, and undoubtedly existed as a cement.

[1] A. J. Jukes-Browne, Quart. Journ. Geol. Soc. vol. lviii (1902) p. 284.

In the case of the calcium-carbonate of these rocks, much of it presumably resulted from chemical precipitation; but, at the same time, it appears that a fair proportion must have been detrital in character.

IV. Mineralogical Characteristics of the Finer Material and Distribution of Mineral Species.

The following is a list of localities from which samples have been collected for petrological study:—

Lower Breccias and Lower Sandstones.

1. Berry Head, south of Brixham. Sandstone.
2. Torre. Sandstone.
3. The Ness, west of Teignmouth. Breccia.
4. The Clerk Rock, east of Teignmouth. Breccia.
5. Heavitree, near Exeter. Breccia and sandstone.
6. Yeoford Junction, north of. Breccia.
7. Hollis Head, near Killerton. Breccia and sandstone.
8. East of Langley, north of Wiveliscombe. Breccia.
9. Topsham (Redcow). Sandstone.
10. Topsham (railway-bridge). Sandstone.
11. Sandygate. Sandstone.
12. Honiton Clyst. Sandstone.
13. Monkerton, near Pinhoe. Sandstone.
14. Gipsy Hill, near Pinhoe. Sand.
15. Broad Clyst Heath. Sand.
16. Digby's Asylum. Sandstone.
17. Brampford Speke. Sandstone.
18. East Town, east of Totland. Sand.
19. Wiveliscombe, south of Castle Hill. Marly sandstone.
20. Stogumber. Sand.
21. Elworthy, outlier near. Sand.

Lower Marls.

22. St. Mary's Clyst. Sandstone.
23. Hulham, near Exmouth. Sandstone.
24. Raddon Quarry, near Thoverton. Marl.
25. Uffculm, south of. Marl and sandstone.
26. Wiveliscombe, east of. Sandstone.

Pebble-Bed.

27. Budleigh Salterton, coast-section, samples taken every 10 feet from base to summit. Sand.
28. Woodbury Castle, 20 feet above the base. Sand.
29. Newton Poppleford. Sand.
30. Fair Mile, near Talaton. Sand.
31. Uffculm, south of. Sand.
32. Burlescombe, Church Quarry. Sand.
33. Milverton Station, quarry at. Calcareous sandstone.
34. Fitzhead, east of Wiveliscombe. Calcareous sandstone.

Upper Sandstones and Marls.

35. Ladram Bay, east of Budleigh Salterton, coast-section. Sandstone.
36. Lyme Regis, deep boring at, depth of 487 feet. Marl.
37. Lyme Regis, deep boring at, depth of 1000 feet. Marl.
38. Lyme Regis, deep boring at, depth of 1200 feet. Marl.
39. Otterton. Marly sandstone.
40. Crowcombe, west of. Sandstone.
41. Bishop's Lydeard, quarry near. Sandstone.
42. North Petherton, Bridgwater area. Sand.
43. Chads Hill, south side of Cannington inlier. Sandstone.
44. Plainsfield, east of, east of the Quantocks. Sand.
45. Cannington Park Farm. Sand.
46. Nynehead, road and quarry near. Sandstone.
47. Wembdon, near Bridgwater. Sandstone.
48. Preston Bowyer. Sandstone.

Upper Keuper Sandstone.

49. Stoke St. Gregory. Sandstone.

The following table (pp. 238–39), in which the numbers refer to the localities mentioned above, presents the distribution of the more important and abundant minerals, exclusive of quartz, which enter into the composition of the New Red sediments.

TABLE I.—*Distribution of mineral*

[+ signifies occurrence. c = above usual percentage.
R = rounded. A = angular.

Locality.	Character of grain.	Fluorspar.	Garnet.	Magnetite.	Pyrite.	Anatase (pyramidal).	Anatase (tabular).	Cassiterite.	Rutile.	Zircon.	Hæmatite.	Ilmenite.	Tourmaline (brown).	Tourmaline (blue).	Tourmaline (tabular).	Barytes.	Brookite.
1.	R.	+	...	+	...	...	+	...	+	+	...	+	c	+	...	...	+
2.	A.	...	...	+	...	...	+	...	+	+	...	+	+	+	...	+	...
3.	A.	...	...	+	...	...	+	...	c	c	...	+	+	+	...	...	c
4.	A.	...	...	+	...	...	+	...	+	+	...	+	+	+	...	...	+
5.	A & R.	...	...	+	...	...	+	...	+	+	...	+	+	c	...	...	+
6.	A.	...	...	+	...	+	+	...	+	+	...	+	+	c	...	...	+
7.	Sub A–A.	...	...	+	...	+	+	...	c	c	...	+	+	+	...	...	+
8.	Sub A–R.	...	r	+	...	+	...	...	+	+	+	+	+	+	..	c	r
9.	R.	...	...	+	...	+	+	...	+	+	...	+	+	+	...	...	...
10.	Sub A–R.	...	...	+	...	...	+	...	+	+	...	+	+	+	+	...	...
11.	Sub A–R.	...	...	+	...	...	...	...	+	c	...	+	+	+	...	+	...
12.	R.	...	...	+	...	+	+	...	+	+	...	+	+	+	...	...	...
13.	Sub A.	...	...	+	...	...	c	...	+	+	...	+	+	c	c	+	+
14.	R.	...	...	+	...	+	+	...	+	+	+	+	+	+	...	...	...
15.	Sub A–R.	...	...	+	...	+	...	...	+	c	...	+	+	+	+	...	...
16.	R.	...	...	+	...	...	...	...	+	+	...	+	+	+	+	...	...
17.	R.	...	...	+	...	+	+	...	c	c	...	+	+	c	...	...	...
18.	Sub A–A.	...	+	+	...	...	...	...	c	c	...	c	+	r	...	...	...
19.	Sub A.	...	...	+	...	+	+	...	c	+	+	+	+	+	+	...	...
20.	Sub A.	...	+	+	...	...	...	...	+	+	...	+	+	r	...	...	...
21.	Sub A–R.	...	+	c	...	...	...	...	+	+	...	c	+	...	...	...	...
22.	Sub A–R.	...	...	+	...	...	+	...	+	c	...	+	+	+	+	...	+
23.	Sub A.	...	c	+	...	...	...	...	+	+	...	+	c	c	...	...	...
24.	A.	...	...	+	...	c	+	...	+	+	+	+	+	+	...	...	...
25.	A.	...	c	+	...	+	+	...	+	+	..	+	c	+	...	...	...
26.	Sub A–R.	...	...	+	...	...	...	...	+	+	...	+	+	+	...	...	...
27.	Sub A.	+	...	+	...	...	+	...	+	+	+	+	c	+	...	...	+
28.	Sub A.	+	...	+	...	+	+	...	+	+	...	+	c	...	...	...	+
29.	Sub A.	...	...	+	...	+	c	...	+	c	...	+	+	+	...	...	...
30.	Sub A.	...	...	+	...	...	+	...	+	+	+	+	c	...	...	?	+
31.	Sub A.	...	+	+	...	+	+	...	+	+	...	+	c	+	...	...	...
32.	Sub A.	...	+	+	...	...	...	...	+	+	...	+	c	+	...	...	...
33.	Sub A.	...	c	+	...	...	...	...	+	+	...	+	c	+	...	...	...
34.	Sub A.	...	+	+	...	+	c	?	c	c	...	+	c	+	...	...	...
35.	Sub A.	...	c	+	...	...	+	...	+	+	...	+	+	+	...	...	+
36.	A.	...	+	+	...	+	+	...	+	+	...	+	+	+	...	+	+
37.	A.	...	+	...	...	...	...	...	+	+	...	...	+	+	...	c	...
38.	A.	?	c	...	...	...	...	...	+	...	...	...	+	+	...	...	...
39.	A.	...	+	+	...	...	c	...	+	+	...	+	+	+	...	...	...
40.	Sub A.	...	c	+	..	...	r	...	+	+	...	+	+	+	r	...	...
41.	Sub A.	...	...	+	...	+	c	...	c	+	...	+	+	c	r	...	r
42.	Sub A.	...	c	+	...	+	c	...	+	+	...	c	+	r	...	...	+
43.	Sub A.	...	r	+	...	r	c	...	+	+	...	c	+	+	...	...	+
44.	Sub A.	...	...	+	...	r	c	...	+	+	...	c	+	+	r	+	...
45.	Sub A.	...	+	+	...	+	+	...	+	+	...	+	+	+	...	...	...
46.	Sub A.	...	+	+	...	+	c	...	+	+	...	c	+	r	...	...	+
47.	Sub A.	...	+	+	...	...	+	...	+	+	...	c	+	r	...	...	...
48.	Sub A.	...	+	+	...	...	+	...	+	+	+	+	+	+	...	...	...
49.	Sub A–A.	...	c	+	+	...	...	...	+	+	...	+	+	+	...	...	...

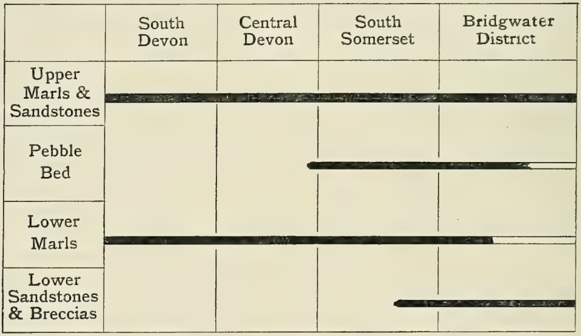
r = below usual percentage. ? = occurrence doubtful.
Sub A = subangular.]

Cordierite.	Sillimanite.	Staurolite.	Topaz.	Actinolite.	Biotite.	Chlorite.	Muscovite.	Orthoclase.	Sphene.	Cyanite.	Microcline.	Plagioclase.	Leucoxene.	Pinite.	Serpentine.	Shimmer-aggregates.	
...	...	c	...	...	+	+	+	+	...	...	+	+	c	...	+	+	Lower Breccias.
...	...	+	...	...	c	+	+	+	+	...	+	+	+	...	...	...	
...	...	+	...	...	+	+	+	+	...	...	...	...	c	...	...	...	
...	...	+	...	...	...	+	+	+	...	...	...	...	+	...	+	+	
...	+	+	+	...	+	...	+	+	+	...	...	+	c	...	+	...	
...	...	+	...	...	+	+	+	c	+	...	+	c	+	...	...	...	
...	...	c	...	...	...	+	+	+	+	...	+	+	c	...	...	...	
...	...	+	...	...	...	+	...	r	...	...	...	...	...	...	...	...	
...	+	+	...	...	...	+	+	+	+	...	+	+	+	...	...	+	Lower Sandstones.
...	...	+	...	...	...	...	...	+	...	...	+	+	+	...	...	...	
...	...	...	...	...	+	+	+	...	...	...	...	...	c	...	...	+	
...	...	+	...	...	...	?	+	c	+	...	+	+	c	?	...	+	
...	...	+	...	...	...	+	+	+	+	...	...	+	+	...	+	...	
...	...	+	...	...	...	...	+	+	...	...	+	c	+	...	...	...	
...	...	+	...	...	...	...	+	+	...	...	+	+	+	?	...	+	
...	...	+	...	...	...	...	+	+	+	...	c	+	+	...	...	...	
...	...	+	...	...	...	+	+	+	...	...	...	+	+	...	...	...	
r	...	+	...	...	...	...	...	+	...	...	...	...	+	...	...	...	
...	...	+	...	...	...	...	+	+	...	...	...	...	+	...	...	+	
...	...	+	...	...	...	...	...	+	...	...	...	...	+	...	...	...	
...	...	c	...	...	...	...	...	+	...	...	...	...	+	...	...	...	
...	+	+	...	...	...	+	+	...	+	...	...	...	+	+	+	+	Lower Marls.
...	...	+	...	...	...	+	+	+	+	...	+	+	+	?	...	...	
...	...	+	...	...	...	...	+	+	+	...	...	?	...	...	...	...	
...	...	+	...	...	...	...	+	c	...	...	+	+	+	...	...	...	
...	...	+	...	...	...	+	+	+	+	...	+	+	+	...	...	...	
...	+	c	...	...	+	+	+	+	+	...	+	+	c	...	+	c	Pebble-Bed.
...	...	c	...	...	...	...	c	+	?	...	+	+	+	...	...	+	
...	?	c	...	...	+	+	c	+	...	?	+	+	+	+	+	+	
...	...	c	...	...	c	c	+	+	...	...	+	+	+	...	...	+	
...	...	c	...	...	+	+	+	+	+	...	+	+	+	...	...	+	
...	...	c	+	...	...	...	+	+	...	...	+	+	+	...	...	+	
...	...	c	...	...	...	...	c	+	...	...	+	+	+	...	...	+	
...	...	c	...	...	...	+	+	+	+	+	+	+	c	...	...	+	
...	...	+	...	...	+	+	c	+	...	+	+	+	+	+	+	+	Upper Marls, Sandstones, and Upper Keuper Sandstones.
...	...	+	...	...	...	...	+	+	...	...	?	?	+	...	...	...	
...	...	...	...	...	...	...	+	+	+	...	?	?	?	...	...	...	
...	...	...	...	+	...	...	+	+	+	...	?	?	+	...	...	...	
...	+	...	...	...	+	...	c	+	+	...	+	+	+	+	+	+	
...	...	+	...	...	...	+	+	+	...	...	...	...	+	...	...	...	
...	...	r	...	...	...	...	+	+	...	...	+	+	+	...	...	...	
...	...	r	...	...	...	...	+	+	...	...	r	...	+	...	...	...	
...	...	+	...	...	+	+	+	+	...	...	...	...	+	...	...	...	
...	...	+	...	...	...	...	...	+	...	...	...	+	+	...	...	...	
...	...	r	...	...	...	...	...	+	...	...	...	...	+	...	...	...	
...	...	+	...	...	...	...	...	r	+	...	...	...	+	...	...	...	
...	...	r	...	...	...	...	...	r	+	...	...	...	+	...	...	...	
...	...	+	...	...	...	+	...	r	...	...	...	...	+	...	...	+	
...	...	+	...	...	...	...	...	+	...	...	...	...	+	...	...	...	

It will at once be seen from Table I that, although there is a general similarity in the mineral contents of the various divisions of the New Red, it is possible to observe radical differences, which become more apparent the more closely the rocks are studied.

The distribution of garnets shown in Table II (below) brings out clearly how, not only various horizons in the New Red, but also the same horizons in different districts, may exhibit special mineralogical characteristics. The same point may be urged with reference to the distribution of staurolite, tourmaline, and several other minerals.

Table II, *illustrating the vertical and horizontal distribution of garnet in the New Red rocks.*



There are, however, a certain number of mineral species which are present in almost every sediment, and thus by themselves throw but little light on the origin of a deposit; at the same time, the relative abundance of any mineral at different localities on the same horizon is most important.

To sum up the results expressed in the two tables given above, it may be stated that the Lower Breccias and Sandstones are fairly constant as to their mineral contents. In the extreme south of Devon they approximate in composition more closely to the southern part of the Pebble-Bed: for staurolite is common, and fluorspar also occurs, in both. They contain, and are characterized by, an unusually large quantity of iron-ores, brookite, rutile, felspars, and felsitic material, but above all by the abundance of blue acicular tourmaline, either free or embedded in quartz. Most of the quartz gives uniform extinction, and there is, in South Devon, a total absence of garnets. In Somerset, however, garnets are fairly common in the Lower Sandstones around the inliers of Cannington and Quantock.

In the Lower Marls much more of the quartz shows undulose

extinctions; blue acicular tourmaline becomes less frequent, but the brown stumpy prisms of this mineral are more common; brookite is scarce, and iron-ores are less abundant. In South Devon garnets first appear on this horizon (Table II).

The Pebble-Bed in Devon and Somerset presents two more or less distinct types: one existing from the south coast to the neighbourhood of Uffculm, the other obtaining from Uffculm northwards. It will be convenient to refer to these respectively as the southern and the northern type. Both types are bound together by the prevalence of staurolite, and they may be compared and contrasted as follows:—

Southern type.	*Northern type.*
Staurolite abundant.	Staurolite abundant.
Blue tourmaline rare.	Blue tourmaline more common.
Brookite rare.	Brookite more common.
Garnets absent.	Garnets present.
Fluorspar present.	Fluorspar absent.
Ferruginous cement.	Ferruginous and calcareous cement.

All along its course the Pebble-Bed contains many minute fragments of schistose material; and much of the quartz, especially in the south, has undulose extinction.

The Upper Marls and Sandstones, from south to north, are characterized by an abundance of pink garnets and the general occurrence of brookite; and in the south more especially by the occasional presence of actinolite. Staurolite is not so abundant in these rocks as in the Pebble-Bed, and, in addition, it is in these upper beds that we most usually meet with such cementing-materials as barytes, celestine, and gypsum in quantity. Barytes, however, occurs less plentifully at certain localities on other horizons, both in the Red rocks of this district and in those of the Midlands.

V. Conclusions.

A most important factor in the study of these sediments is the relation that they bear to the pre-existing rocks of the West of England. In dealing with this subject several questions arise, the most prominent of which is—What rocks were capable of yielding the material which entered into the composition of the New Red Sandstone? There is no doubt that most of the older rocks, now exposed at the surface, supplied detritus; but it does not appear possible, as pointed out in my previous paper, for them to have furnished all the mineral species detected in the heavy residues.

In the Lower Breccias and Sandstones staurolite occurs most plentifully in the southernmost exposures; and, taking into consideration the evident local origin of these deposits, as proved by the larger rock-fragments, it seems safe to assume that they were laid down not far from a series of staurolite-bearing rocks. No such rocks, however, exist in this part of England, but, as previously suggested, probably lay to the south of the present coast-line.

From a study of the distribution and quantity of certain mineral species, it is possible in most instances to gather some idea of the relative amounts of material derived from various sources. This is more especially true in the case of the Lower Breccias and Sandstones and the Pebble-Bed. The material forming the marls, however, as might be expected from its finely comminuted nature, appears to have been supplied from all directions, and by a greater variety of rocks than those yielding detritus towards the formation of the other New Red sediments.

With regard to the source of the various mineral species it is most difficult to speak, except in certain cases; but, so far as can be judged, all the minerals detected in the New Red deposits, with the exception of staurolite, could be supplied by the older rocks of the West of England. The greater abundance of such minerals as blue tourmaline, topaz, rutile, and brookite appears to indicate that the rocks in which they occur were largely derived from the granite-masses of Devon and Cornwall, but more especially points to their attendant metamorphic rocks and veinstones.

The garnets of the New Red deposits are clearly in no way dependent on the distribution of staurolite, but, on the contrary, are of most frequent occurrence in the northern part of the district where staurolite is less abundant. The fact that garnet, in the Pebble-Bed, makes its appearance together with an increased proportion of blue tourmaline, points to its derivation, at any rate in part, from the metamorphic rocks surrounding the West of England granites. Its absence from certain horizons might be accounted for, either by the direction of the sediment-bearing currents, or by the extremely local occurrence of garnets in the metamorphic aureoles of this district. It is only where subordinate calcareous bands of the Devonian and Carboniferous rocks and diabase-intrusions come within the influence of the granites that this mineral has been produced. It is not suggested that all the garnets in the New Red rocks were supplied by these metamorphic areas; but, should it be so, it would appear from the distribution of this mineral that all the New Red rocks of North Devon and West Somerset were formed in part of material carried from the west and south-west.

The Lower Breccias have always been considered as deposits derived from sources near at hand, for, as pointed out by De La Beche, Godwin-Austen, Conybeare & Phillips, and Mr. R. H. Worth, among the rock-fragments found in them are numerous examples of well-known rock-types present in Devon. The minerals and grains forming the finer material of these deposits point towards the same conclusion; but, in addition, especially in South Devon, they suggest strongly the influence of certain rock-masses non-existent within the south-western area as now known. There is, also, nothing in the finer material to prove that the granite-masses themselves were undergoing denudation at the time when the Lower Breccias were being deposited.

The climatic conditions[1] under which the Lower Breccias and Sandstones were deposited have been discussed for these and similar rocks. The idea of the existence of desertic and lateritic conditions[2] is, it seems, made more tenable when we consider the prevalence of millet-seed sands and the increased proportion of plagioclase-felspars[3] in these deposits.

The Lower Marls, and the Upper Sandstones and Marls, as regards composition, appear to be the most uniform members of the New Red Sandstone, a fact explained partly by their lithological character and partly by their mode of deposition. As stated before, they have evidently had a more complex source than the other members of the New Red, and were deposited chiefly from sediment-bearing currents which had no constant direction for any length of time.

Again, in the case of the Upper Sandstones and Marls it is most difficult, in view of their transgression northwards and westwards on to older rocks, to say how much of the material of which they are composed is of direct origin from the parent source, and how much has been derived from pre-existing New Red deposits.

Such problems will only be possible of solution when the petrology of the older sedimentary rocks has received adequate attention.

In conclusion, I wish to express my indebtedness to Prof. Sollas for much assistance and encouragement during the early stages of this work; to Mr. Ralph Morgan and Mr. Robert Hancock, of Exeter, as also to Mr. W. G. Churchward, F.G.S., of Teignmouth, for their kindness in collecting for me many samples of the New Red rocks; and to Mr. Ussher, F.G.S., for allowing me to work on material collected by him in Somerset.

EXPLANATION OF PLATE XII.

Fig. 1 *a*. Anatase: group of crystals in parallel growth, tabular parallel to the base $\{001\}$, from the Pebble-Bed of Newton Poppleford (Devon). × about 115. (See pp. 231–32.)

1 *b*. Anatase, with low pyramids of such form as $\{h h l\}$, from the Lower Breccias of the Ness, Teignmouth (Devon). × about 100. (See p. 232.)

1 *c*. Anatase similar to fig. 1 *a*, from the Lower Sandstones of Honiton Clyst (Devon). × about 200. (See pp. 231–32.)

2 *a*. Brookite, pale-yellow crystal from the Lower Breccias of the Ness, Teignmouth (Devon). × about 250. (See p. 238.)

2 *b*. Brookite, an almost colourless, somewhat rounded crystal, from the Lower Marls of Raddon Quarry, near Thoverton (Devon). × about 250. (See p. 238.)

2 *c*. Brookite, an almost colourless crystal, from the Lower Sandstones of Monkerton, near Pinhoe (Devon). × about 1000. (See p. 238.)

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[1] J. G. Goodchild, Trans. Geol. Soc. Edin. vol. vii (1893–99) p. 203; and J. A. Phillips, Quart. Journ. Geol. Soc. vol. xxxviii (1882) p. 110.

[2] J. J. H. Teall, Proc. Geol. Assoc. vol. xvi (1899) p. 148.

[3] W. Mackie, Trans. Geol. Soc. Edin. vol. vii (1893–99) p. 443; see also T. G. Bonney, Proc. Liverp. Geol. Soc. vol. ix, pt. ii (1902) p. 220.

Fig. 3. Anatase, steeply pyramidal, with small basal plane, from the Pebble-Bed of Woodbury Castle (South Devon). × about 150. (See p. 232.)

4 *a*. Staurolite, an almost perfect crystal showing the forms {010}, {110}, {101}, and {001}, from the recent blown sands of Newgale (Pembrokeshire). × 100. (See pp. 234–35.)

4 *b*. Staurolite, similar crystal to the foregoing, from the Pliocene deposits of Lenham (Kent). × about 100. (See pp. 234–35.)

4 *c*. Staurolite, grain bounded by cleavage-faces, the most usual mode of occurrence in the Red rocks of the West of England and the Midlands, from the Pebble-Bed of Budleigh Salterton (Devon). × about 100. (See p. 234.)

5. Anatase, imperfect octahedral crystal with moderately large basal plane, from the Lower Breccias of the Parson and Clerk Rocks, Teignmouth (Devon). × about 150. (See p. 232.)

6 *a*, *b*, *c*. Tourmaline, blue hexagonal crystals flattened parallel to the base, and modified by narrow rhombohedral planes, from the Lower Sandstones of Monkerton, near Pinhoe (Devon). × about 100. (See p. 233.)

7. Anatase, tabular crystals growing on decomposing ilmenite from the Keuper Sandstone of Weston (Cheshire). (From a preparation supplied by Mr. J. B. Scrivenor, M.A., F.G.S.) × about 100. (See p. 232.)

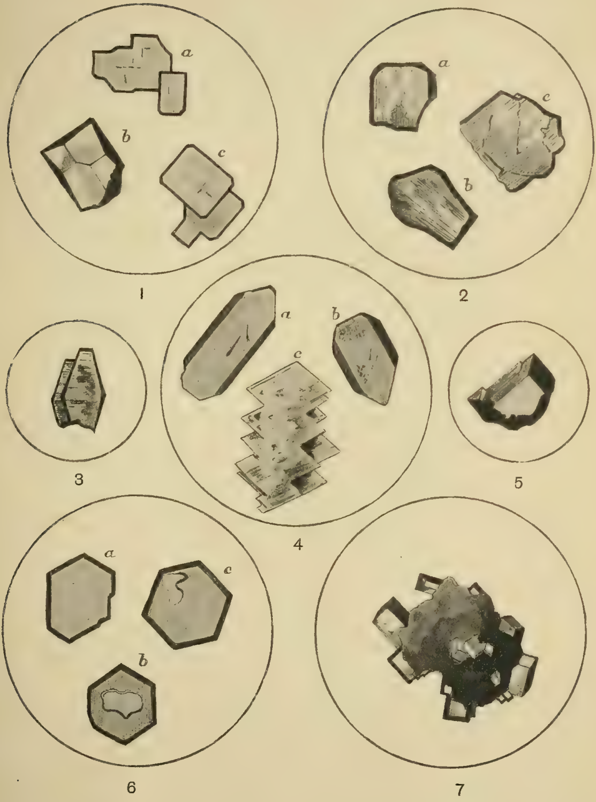
Discussion.

Dr. J. W. Evans laid stress on the importance of work on sand-grains. He suggested that the tabular crystals of anatase might be cleavage-plates following the perfect basal cleavage.

Mr. G. Barrow remarked on the interest of the Author's table showing the distribution of the minerals at different horizons. In the lowest beds, blue schorl-needles seemed especially abundant; these were of local origin, as one would rather expect. Higher in the series staurolite became common; but this mineral was not of local origin, being possibly derived from the rocks in which the adjacent English Channel (clearly a submerged valley) had been cut. These rocks were almost certainly, in the main, pre-Cambrian and metamorphosed. There was a possible doubt as to the origin of the garnets: their local source, in part at least, would be proved by the presence of the pneumatolytic type, with the characteristic well-marked banding, or parallel planes of growth. Were such garnets found in the sediments examined by the Author?

The President (Prof. Sollas) complimented the Author on the successful manner in which he had brought the skill of the mineralogist to bear on the interpretation of these minute constituents of sedimentary beds. The paper was of interest, not only for its numerous observations in detail, but for its general conclusions; and he would like to enquire whether the Author still looked to Armorica as the source of some of the minerals that he had determined.

The Author thanked the previous speakers for their kind remarks relative to his work, and, in reply, stated that although in some instances tables of anatase might be produced in the manner



H. H. Thomas, del. *Bemrose, Collo., Derby.*

MINERALS FROM THE NEW RED SANDSTONE, ETC.

suggested by Dr. Evans, in the New Red rocks there were sufficiently numerous instances of tabular crystals growing on ilmenite, and crystals showing very low pyramid-planes, to preclude the possibility of the tabular crystals being due to cleavage only.

In reply to Mr. Barrow, he remarked that the blue acicular tourmaline was not confined to the lower divisions of the New Red Sandstone, but was exceptionally abundant in the Lower Breccias and Sandstones. Most of the garnet in these deposits appeared to be a pale-pink variety of that mineral, such as was usually met with in true contact-deposits. He could not definitely state that he had recognized any garnets to which a pneumatolytic origin could be assigned.

With reference to the remarks made by the President, he said that, while it was possible to derive most of the minerals and grains from rocks known to occur in the West of England, it was impossible to regard the staurolite as having come from that district. The parent rock of this mineral certainly lay to the south of the present coast-line of Devon, and, as contended in his earlier paper, in the old land-area of Armorica.

16. *On the* Boulders *of the* Cambridge Drift: *their* Distribution *and* Origin.

By Robert Heron Rastall, M.A., F.G.S., and James Romanes, B.A. (Read April 28th, 1909.)

Contents.

I. Introduction.

The origin and distribution of the boulders of the Glacial Drift of Cambridgeshire and the adjoining counties is a subject of great interest on which hitherto little work has been done. Although much has been written on the Glacial deposits of this district as a whole, little attempt has been made to examine in detail the types of rock represented in the Boulder-Clay and to trace them to their sources. During the last seven or eight years a large amount of material has been collected, both by the members of the Sedgwick Club and by other independent workers. A brief account of some of the results obtained up to that time was given by Mr. Fearnsides in the official hand-book compiled for the Cambridge meeting of the British Association in 1904, and a short paper entitled 'On Boulders from the Cambridge Drift, collected by the Sedgwick Club'[1] was published in the same year by one of the present authors. Since that date much new material has been collected, and the whole has now come into our hands. The additional evidence thus made available, shows that the conclusions set forth in the previous publications can be considerably extended.

The total number of boulders collected now amounts to many hundreds; and, as naturally would be expected, a great number of them, perhaps the majority, are of uncertain origin, since it is clear that the field of derivation is a very wide one. However, a large number of rock-types have been identified, either provisionally or with certainty; while in the case of many more the identification is highly probable.

II. Summary of Previous Literature.

The following list does not claim to be a complete bibliography of the subject. It includes only a few of the more important

[1] Geol. Mag. 1904, p. 542.

memoirs and papers, and no references have been given to general text-books :—

T. G. Bonney. 'Notes on the Roslyn Hill Clay-Pit' Geol. Mag. 1872, p. 403; and Proc. Camb. Phil. Soc. pt. xiii, vol. ii (1872) p. 268.

A. J. Jukes-Browne. Geological Map of the Neighbourhood of Cambridge. 1874.

T. G. Bonney. 'Cambridgeshire Geology' 8vo, Cambridge, 1875.

A. J. Jukes-Browne. 'The Post-Tertiary Deposits of Cambridgeshire' (Sedgwick Prize Essay for 1876) 1878.

W. H. Penning & A. J. Jukes-Browne. 'The Geology of the Neighbourhood of Cambridge' (Explanation of Quarter-Sheet 51 S.W., &c.) Mem. Geol. Surv. 1881.

W. Whitaker. 'On a Deep Channel of Drift in the Valley of the Cam (Essex)' Quart. Journ. Geol. Soc. vol. xlvi (1890) p. 333.

A. Harker. 'Norwegian Rocks in the English Boulder-Clays' Geol. Mag. 1894, p. 334.

H. H. Howorth. 'The Chalky Clay of the Fenland, &c.' Quart. Journ. Geol. Soc. vol. li (1895) p. 504.

H. H. Howorth. 'Erratic Boulders & Foreign Stones in the Drift-Deposits of Eastern England, &c.' Geol. Mag. 1897, pp. 123 & 153.

F. R. C. Reed. 'Handbook to the Geology of Cambridgeshire' 1897.

F. R. C. Reed. 'Note on a Large Boulder at Wimpole Hall (Cambs.)' Geol. Mag. 1898, p. 267.

H. B. Woodward. 'On some Disturbances in the Chalk near Royston (Hertfordshire)' Quart. Journ. Geol. Soc. vol. lix (1903) p. 362.

W. G. Fearnsides. 'Handbook to the Natural History of Cambridgeshire' (Ed. Marr & Shipley) Brit. Assoc. (Cambridge) 1904, p. 37.

R. H. Rastall. 'On Boulders from the Cambridge District, collected by the Sedgwick Club' Rep. Brit. Assoc. (Cambridge) 1904, p. 571; see also Geol. Mag. 1904, p. 542.

T. G. Bonney. 'On the Relations of the Chalk & Boulder-Clay near Royston (Hertfordshire)' Quart. Journ. Geol. Soc. vol. lxii (1906) p. 491.

W. Hill. 'On a Deep Channel of Drift at Hitchin (Hertfordshire)' Quart. Journ. Geol. Soc. vol. lxiv (1908) p. 8.

III. Method of Investigation.

Generally speaking, large boulders are rare in the district round Cambridge, and very few are to be seen scattered over the surface; this rarity may be due to the fact that they never existed, but much more probably to artificial causes. As is well known, building-stone is non-existent in the immediate neighbourhood, and it is only natural that for the rougher kinds of building and for pavements any hard material which lay close at hand would be utilized. In the town of Cambridge and in all the surrounding villages there are to be seen great stretches of cobble-stone pavement, consisting chiefly of rounded and subangular blocks of various kinds and often of considerable size. Many of these pavements evidently date from a time when transport was costly and difficult, and it seems highly probable that the material was obtained close at hand. Now, the only conceivable source for these stones is the Drift or its derivatives, and the total bulk of them must be enormous. That this is the true cause of the absence of surface-

boulders is shown by the fact that in many pits similar blocks are found in undisturbed gravel. However, on account of the possibility of artificial transport for considerable distances by land or especially by water, it is unsafe to found any conclusions on these pavements, and all such have been here excluded.

The method pursued in the investigation was as follows: all the specimens were carefully labelled as soon as collected, and any of uncertain origin were rejected. The great majority of the specimens were collected from gravel-pits in actual operation, or from the surface of arable land where there is little or no likelihood of transport by human agency. Besides these, there were found in the Sedgwick Museum many specimens of undoubted authenticity collected from the Barrington and Barnwell gravels.

After all the material had been critically examined in this way, the specimens were sorted out according to locality, and for this purpose the whole area was divided into districts, of which the following is a list:—

(1) Cambridge and neighbourhood;
(2) Hardwick and St. Neots Road;
(3) Lords Bridge, Barton, and Comberton;
(4) Barrington and Foxton;
(5) Kingston and Toft;
(6) Whittlesford, Pampisford, Hinxton, and Linton;
(7) Chesterford.

Petrological Examination.

In view of the detailed petrological investigation of the material, thin slices for microscopic examination were prepared from the most promising specimens; all the slices described in the British Association Report and in the Geological Magazine were carefully re-examined in the light of further knowledge, and a large number of new ones were obtained, making a total of about 150. The specimens which were not sliced were compared with typical rocks in the Sedgwick Museum and elsewhere, and a number which were believed to be of Scottish origin were taken to Edinburgh and compared with specimens in the Royal Scottish Museum. Our thanks are due to Mr. R. Campbell, M.A., B.Sc., of the Edinburgh University, and Mr. W. T. Gordon, M.A., B.Sc., of Emmanuel College, Cambridge, for their kind assistance in identifying several of the specimens. Full details of the results obtained by these means are given in later sections.

When this examination was complete, the rock-types recognized with certainty were plotted by means of conventional signs on a 1-inch Ordnance map of the district, so that the distribution of boulders of varying origin could be seen in a graphic manner. The results thus obtained will be discussed in the final section of this paper.

IV. Short Account of the Glacial Drift of Cambridgeshire.

In the area under consideration there is a complete absence of any pre-Glacial strata younger than the base of the Upper Chalk. Farther south this great stratigraphical break is partly filled up by the occurrence of certain Tertiary deposits, though in no part of the country is the succession complete right up to the Pleistocene.

In Cambridgeshire there is no evidence as to whether these Tertiary beds were ever deposited; but, even if they were once present, they must have been completely removed before the glaciation of the district began. We therefore find the Glacial deposits resting upon an old eroded land-surface, on which beds from the Upper Jurassic to the base of the Upper Chalk are exposed.

In East Anglia the general succession of the Glacial beds seems to be as follows:—

Plateau-gravels;
Great Chalky Boulder-Clay;
Contorted Drift;
Cromer Till.

As, however, we move westwards from the coast, the lower beds are seen to disappear; and around Cambridge the two upper members alone can be recognized, and of these two the Chalky Boulder-Clay is by far the thicker and more abundant. As might be expected, the Chalky Boulder-Clay, having been formed on an irregular land-surface, shows great variation in thickness. In many cases it seems to have filled up deep pre-Glacial valleys, and borings have proved thicknesses up to nearly 500 feet; a good example of this occurs at Newport just outside the area here dealt with: a boring there failed to reach the base of the Drift at a depth of 340 feet. In such cases the base of the Drift is far below sea-level, and consequently these valleys must have been formed at a time when the land stood considerably higher than now.

At the present time the Boulder-Clay is found principally on the higher ground, as much of it has been removed by post-Glacial denudation from the recent valleys. In composition the Boulder-Clay varies considerably, according to the nature of the bed on which it is resting; where this is Chalk, the matrix is of a greyish colour, and evidently consists largely of finely ground-up chalk. Where it rests upon Gault or any of the Jurassic clays, it takes on a much bluer colour and a more sticky consistency; indeed, in such cases it is often hard to draw a sharp line where the Boulder-Clay ends and the other begins, so closely may it approximate in colour and texture to the underlying clays.

Throughout the Boulder-Clay are scattered innumerable fragments of rock. By far the commonest types are flints together with lumps of Chalk, Gault, etc., which have escaped being ground up; fragments of more rounded sandstone and limestone are also common. These boulders are mostly of quite a small size, not generally

exceeding 2 feet in diameter. There occur, however, in the Drift huge masses of Chalk or Jurassic clay usually spoken of as 'erratics.' These must also be regarded as true boulders, although they may measure hundreds of yards in length. The best known example of this occurs in the Roslyn Pit, near Ely, where a huge mass of Chalk, Cambridge Greensand, and Gault has been transported by ice and laid down in a hollow scooped out of the Kimmeridge Clay.

Besides the boulders of obvious local origin there occur scattered through the clay a considerable number of rocks, both sedimentary and igneous, which cannot be matched from any known locality in the Cambridge area. The presence of these we are forced to attribute to transport by ice originating in distant and widely-separated districts.

The High-Level Gravels.

In some places patches of coarse gravel are found which seem to overlie the Chalky Boulder-Clay, sometimes overlapping it and resting directly upon the Chalk. These gravels occur in most instances on the higher ground: for instance, on Barrington Hill patches of coarse gravel are found at about 350 feet above sea-level. These gravels are distinguished from the normal Boulder-Clay by a difference in the proportion of coarse and fine material rather than by any difference in the materials themselves; in some cases there are patches and seams of sand: in fact, they represent exactly just such a deposit as might be expected to result from the washing-away of much of the finer material of the normal Boulder-Clay. The gravels are generally unstratified, and the rocks of local origin show little if any more rounding than those of the Boulder-Clay. All the evidence available points to the fact that these high-level gravels are simply the heavier residue of Boulder-Clay which has been weathered out *in situ.*

Those who maintain that the Boulder-Clay is a marine deposit attribute the coarse gravels to re-sorting by wave-action as the land gradually emerged.

Post-Glacial Deposits.

Of the recent deposits we may distinguish for our purpose:—

(1) The gravels of the ancient river-system; and
(2) The gravels of the present river-system.

Apart from their palæontological contents, these are all very similar, varying from coarse gravels to sand and loam. They represent the residue of material which has been derived by denudation from the steeper slopes; and a large part of this must represent the Glacial deposits known to be absent from the sides of the valleys. Although such material has suffered a certain amount of transport since its deposition by the ice, it cannot have been brought from any locality outside the drainage-area of the river-system by which it was deposited. In any case, the fact of real

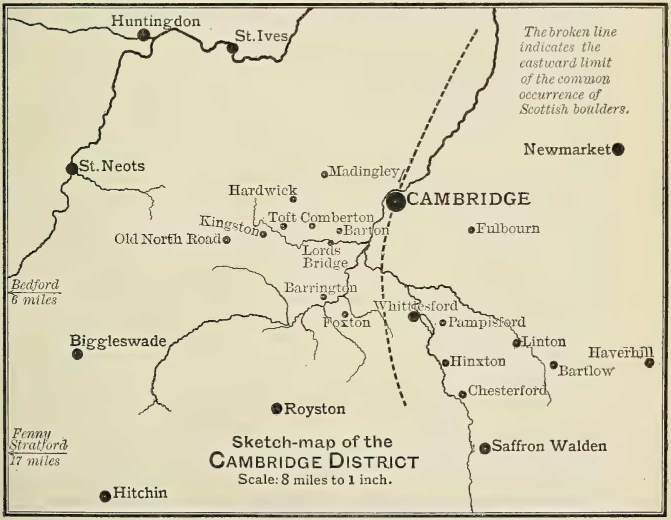
importance to us remains unaltered: namely, that all the gravels represent the heavier portions of the Boulder-Clay, and have suffered little or no transport since their deposition by the ice. We are, therefore, perfectly safe in collecting our evidence from boulders, irrespective of the fact whether they have been obtained from the true Boulder-Clay or from the gravels.

V. Details of each District in Separate Sections.

(1) Cambridge and neighbourhood.

Here are included all specimens obtained within the borough of Cambridge, Chesterton, Newnham, Girton, Trumpington, Shelford, pits on the Gog-Magog golf-links, and Fulbourn.

In this district there are numerous gravel-pits, either now in



Sketch-map of the CAMBRIDGE DISTRICT
Scale: 8 miles to 1 inch.

working order, or abandoned; and the total amount of material obtained is large. A good many specimens are here included which were preserved in the Sedgwick Museum, and were obtained from the older workings of the Barnwell gravel, now for the most part closed. Any of these which seemed in the least degree doubtful were rejected, but many of them bear labels in the handwriting of

Prof. Hughes and other well-known authorities, and are beyond suspicion.

From this district it has been found possible to identify with certainty a large number of rock-types, and many of them are of unusual interest; in particular, rocks from the Christiania petrographical province are abundant. The most distinctive of these is rhomb-porphyry; not more than five or six specimens of this have been found actually *in situ* within the district here defined, but a large number have been detected in buildings and pavements in Cambridge, and some of quite large size, up to half a cubic foot in volume: both the dyke and lava-facies of this rock are known. Other members of this series include soda-granite and ægirine-granite from Newnham, and from the Barnwell gravel a large specimen of a very fine nepheline-syenite; a slice of this was submitted to Dr. Flett, and was considered by him to show strong affinity to the laurdalite group. Two specimens of nordmarkite and one of nordmarkite-porphyry were also sliced: these have been identified by Prof. Brögger. A large boulder of typical laurvikite was collected many years ago by Prof. Hughes.

In this district also we find in great abundance a rock which has given a great deal of trouble, and is not yet identified. It is a beautiful quartz-porphyry or granite-porphyry, with abundant pink felspars and dihexagonal quartz-crystals set in a rather coarsely crystalline ground-mass. It weathers in a peculiar and very characteristic way. The weathered surface is often remarkably smooth, and commonly yellowish or pale brown in colour. The hexagonal quartz-crystals show up with striking clearness as dark spots. In the short paper in the Geological Magazine for 1904, this was described on the authority of Prof. Sjögren as the Dalecarlia porphyry (p. 542), but this identification appears to be erroneous. Many attempts have been made to ascertain the origin of this rock, though hitherto without success. This is peculiarly unfortunate, since it is one of the most characteristic constituents of the Cambridge Drift, occurring in large numbers in almost all the districts investigated. In this paper it is referred to throughout as 'porphyry *x*.'

Another distinctive type is a dark felsitic rock containing a few quartz-crystals and a good many pink felspars. Under the microscope the rock shows phenocrysts of quartz, plagioclase and alkali-felspar, some perthitic. The ground-mass is microcrystalline, and contains abundant needles of tourmaline in radiating groups. This type has been recognized by Messrs. Campbell and Gordon as occurring plentifully in the conglomerates of the Old Red Sandstone of Forfarshire. It will be referred to throughout as 'the Forfarshire porphyry.'

An interesting rock found in this district is a coarse-grained red granite, represented by two blocks from Barnwell and Milton Road respectively. It consists of quartz, microcline-perthite, oligoclase and biotite, with accessory zircon, and interstitial patches of an

isotropic mineral with two cleavages at 71°, and a very low refractive index. This we identify as fluorspar, and the identification is confirmed by Dr. Bonney.

Rocks clearly referable to the Central Valley of Scotland and the Cheviot district are not common in the immediate neighbourhood of Cambridge, but a few specimens have been found, including North Berwick orthophyres, and Carboniferous or Old Red Sandstone lavas, and both dyke and lava-facies of the Cheviot complex. Some large boulders found in a pit on the Huntingdon road, near the Traveller's Rest inn, may perhaps be referred to the teschenite-group of the Edinburgh district.

There were found in the Sedgwick Museum two specimens of much significance; the labels are almost illegible, but they appear to read 'Observatory, Cambridge,' and 'Drift, Cambridge,' respectively. Both of these bear a very strong resemblance to certain varieties of the Borrowdale lavas, and if they had been found in the North of England they would have been assigned without hesitation to this source. If this determination is correct, their occurrence is of the highest interest.

One specimen of a porphyritic rock with large felspars shows a very strong resemblance to some of the acid apophyses of the Shap and Eskdale granites. This must be considered in connexion with the occurrence of lavas of Borrowdale type just mentioned.

Carboniferous sediments, including both the Limestone and the Millstone Grit, are fairly common; while many sandstones were undoubtedly derived from the Coal-Measures. Two specimens of highly characteristic cellular Magnesian Limestone are also recorded. Jurassic sediments are plentiful, and there is in our collection one specimen from Milton Road of a peculiar silicified oolite, which has a wide distribution in the Cambridge Drift: its origin has not yet been determined. Carstone, Hunstanton Red Rock, and hard, pale, pink Chalk are common to the east and south of Cambridge, but not on the north and west; they are always associated with specimens of *Gryphæa dilatata* bored by *Pholas*, and the distribution of this group is of great importance in delimiting the boundaries of different ice-streams, as will appear later.

Besides these determinable types a large number of specimens of acid and basic igneous rocks, together with gneisses and schists, are found, as to the origin of which it is impossible to say anything definite. Many of these have been examined microscopically, and from this examination at least one fact is clearly apparent, namely, that the majority of the granites and gneisses are derived from an alkaline petrographical province; in nearly all cases the dominant felspar is some form of perthite, and soda-bearing ferromagnesian minerals are equally common. This suggests, at all events, a strong probability that many of them are of Scandinavian origin. Throughout the district dolerites and basalts, both with and without olivine, are very common. We have examined many

specimens, but have not been able to come to any general conclusions as to their place of origin.

As typical examples of the assemblage of boulders to be found in gravel-pits near Cambridge we append lists of rocks recognized in two cases: (i) a pit on the golf-links near the summit of the Gog-Magog Hills; and (ii) a pit now being worked on the Huntingdon Road, near the Traveller's Rest, about a mile from Cambridge.

(i) Pit on Summit of Gog-Magog Hills.

Rhomb-porphyry [2].
Felspar-porphyry.
Grey granite.
Forfarshire porphyry.
Cheviot porphyrite and andesite.
Lavas of Scottish Carboniferous or Old Red Sandstone type.
Dolerite, Basalt } abundant.
Old Red Sandstone.
Carboniferous Limestone.
Millstone Grit.
Great Oolite Limestone.
Oxford Clay (concretions with *Serpula tetragona*).
Bunter pebbles.
Carstone.
Boxstones.
Hunstanton Red Rock and pale pink Chalk.
Bored Gryphæas.
Large grey tabular Lincolnshire Flints.
Very abundant rounded pebbles of hard white Chalk, of northern type.

(ii) Pit on Huntingdon Road, near the Traveller's Rest, 1 mile from Cambridge.

Gravel with sandy seams and brown pipes of the ordinary type. Dr. Bonney thinks that it is more like the plateau-gravels than the Cambridge terrace-gravels. Large boulders are unusually numerous, measuring up to 1 cubic foot. The great majority are sandstone, probably Carboniferous, but other rocks are fairly common. The following are identified, and confirmed by Dr. Bonney:—

Carboniferous Limestone, several, some striated.
Millstone Grit, several.
Basalts, Dolerites } large and unusually well rounded.
Rhomb-porphyry [2].
? Nordmarkite.
Pink granulitic granite, two large specimens.
Orthophyre, of North Berwick type.
? Analcime-dolerite (teschenite) of Forth Valley type.
Cheviot porphyrite and lava.
Coarse white granite.
Crushed gneiss.
Large concretion with *Serpula tetragona*.
A species of *Gryphæa*, intermediate between *arcuata* and *dilatata*.

(2) Hardwick and St. Neots Road: 52 specimens.

From this district only a small number of specimens have been obtained, mostly from arable land, since there are no gravel-pits. Among these a large proportion are easily recognizable, including the following important types:—one rhomb-porphyry, one alkali-syenite, and one ægirine-granite; four specimens of porphyry x, and three of the Forfarshire porphyry. Five specimens are of Cheviot type, and one which was sliced is of especial interest, since it seems to be closely allied to the mugearite-type of Mr. Harker, which is

now known to exist among the Carboniferous rocks of East Lothian. The common pink granulitic granite is represented, and there is a considerable number of metamorphic rocks, which it is noteworthy are schistose rather than gneissose; whereas, in the immediate neighbourhood of Cambridge, gneisses are far more common than schists.

(3) Lords Bridge, Barton, and Comberton: 93 specimens.

In this area a large number of specimens have been found. There are two rhomb-porphyries of the vesicular volcanic facies, one from a mile north-west of Barton Church and one from Comberton. Besides these the Scandinavian province is represented by a soda-granite, an augite-syenite, and another alkali-syenite with a blue soda-amphibole and abundant perthite. Three examples of a coarse felspathic grit are referred to the Sparagmite of Norway. The neighbourhood of Lords Bridge is the locality in which porphyry x was originally discovered, and eleven fine examples were obtained, some fairly large. With these are associated a good example of the Forfarshire porphyry. No less than eighteen boulders, including an analcime-dolerite, seem to belong to the Forth Valley or North Berwick type, and Cheviot lavas are common. Among other types represented are greywackés, possibly Silurian, pink granulites (8), dolerites (12), and numerous specimens of various metamorphic rocks.

(4) Barrington and Foxton: 49 specimens.

The collection from Barrington is not large, but it includes several specimens collected by Prof. Hughes, Mr. Keeping, and others from the Barrington gravels. A very fine rhomb-porphyry collected by Mr. Keeping bears date 1884, but it was apparently not identified at that time. There are moreover a nordmarkite, two nordmarkite-porphyries, five soda-granites, and one ægirine-granite; also an especially fine specimen of Sparagmite, which bears a very strong resemblance to some varieties of the Torridon Sandstone. There is one good porphyry x.

One of the most interesting specimens from Barrington is a porphyritic rock, with large pale pink felspars and quartz set in a dark brown ground-mass. Our special attention was first directed to this rock by Dr. Bonney, who remarked on its similarity to a specimen of the Buchan Ness quartz-porphyry in his collection. It has since been submitted to Mr. R. Campbell, who confirms the identification in this and other cases to be mentioned later.

Seven examples of Cheviot dykes and lavas are included, also six pink granulitic granites. A rather remarkable feature is the rarity or apparent absence of basic igneous rocks, which are so common elsewhere: the only representatives of this group are one specimen each of olivine-basalt and gabbro. Metamorphic rocks also appear to be rare.

(5) Kingston and Toft: 139 specimens.

The rocks of the Scandinavian province are represented in this district by one rhomb-porphyry from Toft and one nordmarkite, together with three Sparagmites. There are five specimens of porphyry *x*, and no less than thirty-one boulders are referred to lavas of the Old Red Sandstone type.

The most important discovery here is a small specimen from Kingston Lodge, which appears to be identical in every respect with the well-known muscovite-granite-porphyry of Dufton Pike, in the Eden Valley near Appleby. Associated with this is a specimen of andesitic composition which much resembles some of the rocks of the Borrowdale Series. In connexion with this occurrence must also be taken into account the two specimens of apparent Borrowdale lavas from Cambridge. These four specimens alone, if rightly identified, and there is not much room for doubt in the case of the porphyry at any rate, seem to go far to establish the occurrence of Lake District boulders in Cambridgeshire, a fact not yet recognized.

Among sedimentary rocks the most interesting are cellular Magnesian Limestone and two examples of the silicified oolite already mentioned. The miscellaneous igneous rocks include 10 pink granulites, 2 gabbros, 14 basalts with and without olivine, 13 dolerites, and a serpentine. Metamorphic rocks, especially schists, are strongly represented. One of the most remarkable of these is a rock which consists very largely of radiating bundles of tourmaline-needles. It is probably a product of metasomatic metamorphism, but no suggestion can be made as to its origin.

Mr. Cowper Reed [1] has described an unusually large boulder at Wimpole Hall. Its weight was estimated at 3 tons. It is lithologically similar to the Spilsby Sandstone, and contains ammonites allied to those recorded from that horizon.

The outstanding features of the collection from this district appear to be the abundance of basic igneous rocks and schists, and the comparative rarity of Scandinavian plutonics.

(6) Whittlesford, Pampisford, Hinxton, and Linton: 100 specimens.

This area has yielded an extremely varied collection of boulders. Scandinavian rocks are represented by five rhomb-porphyries, one having been obtained from each of the following localities—Hinxton, Barrington Hill, Whittlesford, and two from Pampisford. One specimen (sliced) is a typical nordmarkite with arfvedsonite and ægirine. Four specimens of porphyry *x* and one specimen of the Forfarshire porphyry occur, together with one example of the quartz-porphyry which we have mentioned as found in the

[1] Geol. Mag. 1898, p. 267.

Barrington and Foxton district and as identical with the quartz-porphyry of Buchan Ness (Aberdeenshire).

Two specimens are referred to the Central Valley of Scotland; a slice cut from one of these was identified by Mr. G. Barrow as the analcime-dolerite (teschenite) of Car Craig, Firth of Forth. A boulder from Pampisford gravel-pit proves to be an unusually fresh example of a very basic lava; it is a porphyritic rock, with phenocrysts of olivine and augite set in a ground-mass of augite and deep brown glass, with a few laths of felspar. This agrees in every respect with the well-known limburgite of Whitelaw Hill (Haddingtonshire), originally described by Dr. Hatch.[1] The Cheviot type is here strongly represented, there being thirteen specimens.

The sedimentary rocks include Millstone Grit and silicified oolite, together with the assemblage consisting of Red Chalk, bored Gryphæas, and bored white Chalk, all of which are abundant here.

Liver-coloured quartzites from the Bunter pebble-beds are fairly common. Pink granulites are rather abundant; but the basic igneous rocks form the most numerous group in this district, being represented by seventeen specimens.

Among the metamorphic rocks, schists are conspicuous by their almost complete absence—only one being recorded, though the gneisses number six.

A point well worth noting is the similarity between the boulders of this district and those obtained from the pit on the summit of the Gog-Magog Hills, the only important differences being the absence from the latter locality of the Buchan Ness porphyry and metamorphic rocks.

(7) Chesterford: 22 specimens.

The collection from this district is small, but most of the types are represented. A rhomb-porphyry, a syenite, and a specimen of Sparagmite may be assigned to Scandinavian origin. The syenite is a semi-plutonic rock of moderately coarse texture, consisting of alkali-felspars (perthite) and a deep brown amphibole, which may be referred to barkevikite. Some subsidiary red biotite (lepidomelane) and colourless augite are also present. The rock is evidently highly alkaline, and may be conveniently named barkevikite-syenite. It has clear affinities with the rocks of the Christiania province.

One specimen each of the *x* and Forfarshire porphyries occur. The Scottish rocks are represented by one porphyrite of North Berwick type and two of Cheviot-dyke type.

The sedimentary rocks include a silicified limestone, Neocomian grit, and Lincolnshire Red Chalk.

Pink granites and granulites are relatively abundant, and basic igneous rocks also occur.

[1] Trans. Roy. Soc. Edin. vol. xxxvii, 1891–92 (1895) pp. 116–17.

(8) Unclassified Localities.

Included in the general collection are a small number of boulders from various scattered localities, chiefly to the east of Cambridge. The most important of these are two rhomb-porphyries from Haverhill and Bartlow respectively. From St. Ives come two fine specimens of rhomb-porphyry collected by Prof. Hughes. These are accompanied by a syenitic rock consisting essentially of perthite and a great variety of ferromagnesian minerals, including pale blue hornblende, augite, biotite, and probably ægirine. It is probable that nepheline was originally present, though now much altered; and the rock is evidently an alkali-syenite. Another specimen may be described as a quartz-porphyry of alkaline affinities.

It is evident, therefore, from these specimens that rocks of the Christiania province extend over a wide range of country, from Bartlow and Haverhill in the south-east to St. Ives in the north-west. Our researches have not extended farther in the latter direction. Mr. Lamplugh has recently discovered in a gravel-pit, on the north side of the Lea Valley at Ware, a fine boulder of typical laurvikite measuring about 2 feet in diameter.

Hitchin.—The collection from Hitchin is small, comprising only 26 specimens, so that it can in no sense be deemed representative; but it is of considerable importance, since it clearly demonstrates the extension in this direction of ice-transport from the other side of the North Sea. It is well known that the glaciation of the Hitchin district was extensive, and Mr. William Hill has recently called attention to a deep drift-filled channel in the Chalk. The Boulder-Clay is well exposed at the top of the great chalk-pit in which the railway-station stands, and many of our specimens were obtained from here. One very large and particularly fine example of a striated boulder of Carboniferous Limestone from this locality has been placed in the Sedgwick Museum—as a typical example of a boulder from a region of vanished glaciation.

The rock-types recognized from this district include the following: one rhomb-porphyry, and one plutonic rock which consists of perthite and plagioclase (oligoclase) with pale uralitized augite and a little quartz; it seems to be an augite-syenite, with affinities to the monzonites. There is also a specimen of Sparagmite and one of the Forfarshire porphyry. Perhaps the most interesting rock found here is a good example of the type identified as the quartz-porphyry of Buchan Ness. We have obtained specimens of Cheviot dykes and lavas, basic igneous rocks of several kinds, and some metamorphic rocks, of which the most striking is a very highly-altered limestone, containing some peculiar minerals.

Bedfordshire.—There has been placed at our disposal a large and very representative collection of boulders from Bedfordshire,

made by Mr. B. Schön, M.A., F.G.S., of Trinity College, Cambridge, to whom we take this opportunity of expressing our thanks. The greater part of these specimens came from gravel-pits in the neighbourhood of Bedford, and a smaller number from Fenny Stratford. Although not actually obtained from the district dealt with in the present paper, this collection is valuable as showing the westward extension of ice from the North Sea.

Bedford, Kempston, Biddenham, Clapham, etc: 124 specimens.—The Scandinavian petrographical province is represented by six fine specimens of rhomb-porphyry, some of unusually large size, one nordmarkite, and two felspathic grits of Sparagmite type. Porphyry *x* is very abundant throughout the district. The rocks of Central Scotland are represented by one Forfarshire porphyry and three or four orthophyres of North Berwick type. The South of Scotland and the Cheviot district are strongly represented. The usual dolerites and basalts occur. An important fact is the occurrence here of Red Chalk and bored Gryphæas. Metamorphic rocks are common.

Fenny Stratford: 14 specimens.—The chief types represented here are porphyry *x*, Cheviot dykes, and bored Gryphæas.

The collection from this locality is too small to enable any conclusions of value to be drawn from it, but the occurrence of porphyry *x* so far west is worth noticing.

VI. General Remarks.

The abundance of Scandinavian rocks as boulders in the Drifts of Eastern England is well known, and it is not necessary to enlarge upon the occurrence of nordmarkite, laurvikite, rhomb-porphyry, etc., in Lincolnshire and Norfolk, except in so far as this affords general confirmation of our conclusions. We have, therefore, paid no attention to the boulders of Eastern Norfolk, so well seen at Cromer, Sheringham, etc. Since, however, there is some evidence that part at least of the Cambridge ice came in by the Wash, bringing with it Red Chalk and bored Gryphæas from the bed of the North Sea, it was considered desirable to pay some attention to the boulder-assemblage found at Hunstanton. We have examined a collection of boulders from this locality, made by Mr. C. E. Gray, of the Sedgwick Museum, and in this many of the most important Cambridge types are represented. The collection includes 15 rhomb-porphyries, 2 porphyries of *x* type, Cheviot dyke- and lava-rocks; and, most important of all, two good specimens of the Buchan Ness dyke-rock (one of the latter was collected by Prof. Hughes). Some other specimens are indeterminable, but present a general resemblance to the Scottish lavas of Old Red Sandstone age. This evidence, so far as it goes, is very satisfactory, and agrees well with the general character of the Cambridge boulders.

LIST OF RHOMB-PORPHYRIES.

Grantchester.
Chesterton Railway-Bridge.
Traveller's Rest, Huntingdon Road [2].
Vandlebury, Gog-Magog Hills [2].
St. Neots Road, 5 miles from Cambridge.
Comberton.
One mile north of Barton Church.
Barrington [2].
Toft.
Hinxton.
Barrington Hill, Linton.
Whittlesford.
Half a mile north-west of Pampisford Station [2].
Chesterford.
Impington.
Bartlow.
Haverhill.
St. Ives [2].
Hitchin.
Bedford [6].
Hunstanton [15].

NOTE.—Numerous rhomb-porphyries have been observed as paving-stones in Cambridge; but these are excluded, as their origin is uncertain.

VII. SUMMARY AND CONCLUSIONS.

As a result of the detailed and systematic study of the far-travelled constituents of the Cambridge Drift summarized in the preceding sections, certain general conclusions may now be formulated. In the first place, it is obvious that material has been brought together from widely different sources. It is unfortunate that the characters of the Glacial deposits of Cambridgeshire and their derivatives are such that it is impossible to determine with certainty whether the arrival of all these foreign rocks was simultaneous, or whether they were brought by successive ice-streams at different times. It is generally stated that in East Anglia the far-travelled rocks occur only in the lowest division of the Glacial Series, which is also said to be absent from Cambridgeshire. The occurrence, however, of foreign rocks in great abundance throughout the county, and as far west as Bedford, indicates that this division was originally deposited, but subsequently ploughed up by a later ice-sheet, and incorporated in the Chalky Boulder-Clay.

From our mapping of the occurrence of different rock-types there is an indication of a partial and local distribution. One of the most important pieces of evidence bearing on this is the fact that Red Chalk and bored Gryphæas occur chiefly to the east and south of Cambridge, becoming much rarer to the west. On the other hand, Jurassic limestones derived from the Great Oolite and Inferior Oolite are very abundant in the west, about Bourn and Old North Road. Although Chalk is abundant everywhere in the Boulder-Clay, it is noticeable that many of the more markedly rounded and striated pebbles agree better with the hard Chalk of Lincolnshire and Yorkshire than with the soft Chalk of the district. With these are associated many large grey tabular flints, which probably came from Lincolnshire: these have a very wide distribution.

Turning now to the igneous rocks, we find that the highly characteristic and easily determinable types of the Christiania petrographical province are met with over the whole district, and occur in considerable abundance at Bedford. The distribution of

this family can be seen from the list of localities at which rhomb-porphyry has been found (see p. 260). Porphyry x, which is also probably of Scandinavian origin, has an equally wide distribution: it is abundant at Bedford, and has been recorded even from Fenny Stratford. From this it is clear that at one period the whole district was within reach of Scandinavian ice.

The presence of a considerable number of boulders derived from Aberdeenshire and from the Old Red Sandstone conglomerate of Forfarshire presents certain difficulties, as it is inconsistent with the accepted ideas as to the general direction of flow of the ice-streams on the east coast of Scotland. The evidence of striæ, etc., there shows that the ice from the Central Valley and the South-East Highlands spread out in a fan, part moving north-eastwards, parallel to the coast, and part towards the south-east. This, however, probably applies only to the ice in the immediate neighbourhood of the coast; while farther out to sea this stream must have come into contact with the Scandinavian ice, and parts would inevitably be carried southwards. The south-easterly direction of the southern half of the fan affords a ready explanation of the occurrence of boulders from the Central Valley of Scotland and the Cheviots, and such rocks are common in all the drifts of eastern England. Included in our collection are a great number of basalts and dolerites, which we have been unable to identify in detail, but which might well come from the North of England and Central Scotland.

Although the occurrence of Lake District rocks in Cambridgeshire has not hitherto been recorded, there is no difficulty in explaining their presence: one or more streams of ice from the Lake District are known to have crossed the Pennine Chain to the North Sea, and boulders of Shap granite and other unmistakable types are exceedingly common on the Yorkshire coast. Their great rarity in the drifts of Cambridgeshire is rather a matter of surprise than otherwise.

Among the metamorphic rocks are many gneisses and schists, but from these it is next to impossible to draw any conclusions, as most of them could be matched either from the Highlands or from Scandinavia. It is notable that there seems to be a tendency for the gneisses to occur towards the east and the schists towards the west. It is a fact of some significance, as before pointed out, that the majority of the granitic and syenitic gneisses show a distinctly alkaline character, and this is in favour of a Scandinavian origin.

Of the two hypotheses advanced to explain the distribution of the Glacial Drifts over the eastern part of England we prefer that of land-ice, and consistently with this have arrived at the following conclusions:—First, a great ice-sheet advanced from the North Sea and distributed Scandinavian boulders over the whole district: this formed the Cromer Till and Contorted Drift of Norfolk. The direction of movement of this ice-sheet is unknown, but it presumably came from the north-east. At a later stage, ice of British origin moving parallel to the coast became relatively

more powerful and tended to displace the Scandinavian ice towards the east. In the later stages of glaciation the supply of boulders of Scottish origin appears to have diminished, since they are rare to the east of Cambridge, and in the Chalky Boulder-Clay of East Anglia local rocks predominate.

The common occurrence of almost all rock-types at Hitchin and Bedford must be due to the movement of the ice-sheets having been controlled by the Chalk escarpment which runs in a general south-westerly direction.

The map which accompanies this paper (p. 251) is primarily intended to show the distribution of the localities mentioned, but a line has been drawn to indicate approximately the limit of the common occurrence of rocks of Scottish origin. To the west of this line they are abundant, while to the east of it they show a rapid diminution. An exhaustive examination of several gravel-pits at Chippenham, east of Newmarket, and near Mildenhall failed to reveal the presence of any rocks of Scottish or other northern origin. The line therefore probably represents the boundary between the Scottish and the Scandinavian ice when the former had reached its maximum extension.

Finally, we have much pleasure in expressing our gratitude to Dr. Bonney for the kind help and encouragement which we have received from him during the progress of this work.

Discussion.

The President (Prof. Sollas) commented on the value of the paper, as affording exact knowledge concerning the distribution and origin of boulders in the Drift. The Red Chalk, however, was represented by travelled boulders much farther to the west than Bedford: he had himself found examples of this rock in fluvio-glacial gravels exposed in a pit near Burmington, not far from Chipping Norton. This might possibly be explained by an originally greater extension to the west of the outcrop of the Red Chalk. Evidence seemed to be accumulating in favour of the occurrence of two glacial episodes in these islands; but, considering the results obtained in North America and the Alps, it was surprising that so far no proof had been obtained of a larger number.

Prof. Bonney said that he felt sure the Society would agree that they had not often listened to a paper more lucidly presented or more valuable for its facts. These afforded opportunities for a very wide discussion, but he would restrict himself, as far as possible, to indicating their importance. The Authors had traced boulders of Scandinavian rocks over a district extending beyond Cambridge to Bedford and Hitchin. Supposing these to have entered by the Wash, that would be a journey, in a direct line from the coast, of nearly 55 miles in the one case and over 60 miles in the other. Here, then, we had boulders, moving in a south-westerly direction, crossing a stream from Scotland and Northern England, which had

travelled roughly south-south-eastwards; and we must remember that, several years ago, Mr. Rowe had mentioned a similar mixture of these rocks near Felsted in Essex, a place well east of Cambridge and a little south of Hitchin. In like manner, as was already known, erratics from Shap Fell had crossed the same stream of boulders from the north, but in the contrary direction; and the Arenig dispersion also traversed from west to east those from the Lake District and Southern Scotland. These facts were very difficult to explain on any hypothesis; and he would only say that, in seeking to do this, we must remember that, in the Glacial Epoch, the ice in the Scandinavian and the British areas would be likely to advance and retreat simultaneously. The paper, in short, was a very important one, and, as he well knew, had cost the Authors much time and trouble.

The Rev. E. Hill welcomed the paper as a most important addition to Glacial Geology. His own few observations fully agreed with the Authors' descriptions. The only point that he was inclined to question was the entrance of the boulders by way of the Wash. The Great Chalky Boulder-Clay seemed to have come from the west of the Lincolnshire Wolds into Norfolk and Suffolk, but to have found no exit by the Wash. The Yorkshire Clays which were continued east of the Lincolnshire Wolds, into the Cromer Till, seemed to have found no inlet by the Wash. If the Clays did not take this course, was it likely that the boulders should?

Mr. Lamplugh remarked that the Authors' observations were consonant with the general evidence of the East British drifts in showing that the glaciation of this region was effected by an ice-sheet spreading from the basin of the North Sea. This basin appeared to have been itself the main centre of ice-accumulation, and the contribution from the glaciers of Scandinavia probably formed only a subordinate part of the mass. Boulders had been dispersed over the sea-bottom before the advent of the land-ice by which they were again transported, so that it was not always safe to postulate a direct line of travel for them. The geology of the floor of the basin also must be borne in mind in considering the sources of the boulders. The distribution of the North British rocks discussed by the Authors implied that the basin was continuously blocked with the East British ice-sheet until a late stage, and afforded no support to the idea of separate glaciations mentioned by the President.

Dr. A. E. Salter called attention to the remarkably rounded character of the small boulders of rhomb-porphyry exhibited, and stated that he had found pieces of this rock farther west at Grovebury near Leighton Buzzard, and near the crest of the Chalk escarpment at Great Offley (500 feet above Ordnance-Datum), between Hitchin and Luton. Quite recently, Mr. G. Potter had found a rounded boulder, similar to those exhibited, as far south as Fortis Green, Highgate, at 300 feet above Ordnance-Datum in Chalky Boulder-Clay.

The Secretary read the following notes which had been

received from Mr. F. W. Harmer, who was unfortunately unable to be present:—

'The occurrence of igneous erratics in the Glacial deposits of the Fenland seems at first sight anomalous. As far back as 1858, Trimmer had noted the existence of two Boulder-Clays in the Suffolk cliffs, the lower of which he identified with that containing Scandinavian blocks which extends over Northern Europe; the upper characterized by Jurassic débris, which he had traced towards the west. Subsequent investigation has confirmed this view, and has shown that East Anglia was twice invaded by ice, first directly from the North Sea, originating the Contorted Drift with its igneous boulders, Scandinavian or North British; and next by an inland ice-stream, the moraine of which (the Chalky Boulder-Clay) is prevalently of a Cretaceous and Jurassic character. The latter contains, however, although rarely, igneous boulders of similar character to those of the Contorted Drift.

'In a paper, now in the press, I am endeavouring to explain the existence of North Sea drift in a deposit which is plainly of inland derivation. The North Sea drift occupies a large and continuous area in the north-east of Norfolk, but it terminates abruptly to the south along a line running across the country from north-west to south-east, being replaced by the morainic deposit of the inland ice-stream (the Chalky Boulder-Clay), which lies side by side with it, and at the same level. The older deposit was ploughed out, I believe, by the advance of the inland glacier, and was incorporated in the moraine of the latter.

'No Contorted Drift is known in the Fenland region, although its former presence there seems to be indicated by the Scandinavian and other such erratics recorded by the Authors. It does not seem probable that when the North Sea ice overran Norfolk, it could have failed to enter the Fenland by any opening then existing in what is now the Wash. The Wash gap was closed, however, in my opinion, at the later or Chalky Boulder-Clay stage, by the glacier which carried the Cretaceous, Neocomian, and Kimmeridgian material into Mid-Suffolk. Neocomian erratics of Lincolnshire type are exceedingly common in West Norfolk, and they may be traced thence in a continuous trail to the south-east, but there is no evidence whatever of any ice-drift during the Chalky Boulder-Clay period, south-westwards from the Wash. It would seem to follow, therefore, that the igneous boulders, not only of the Chalky Boulder-Clay of Norfolk, but of the Fenland also, are derivative from some North Sea deposit of Contorted-Drift age, formerly existing in the regions in question.'

Prof. W. W. Watts remarked that, although the Authors had wisely refrained from much theory, they had obtained a store of facts, which would do much to influence future theories. In his judgment the ice-sheet theory seemed to present a more consistent story of the events of the Glacial Epoch than any other known to him.

Mr. Rastall, replying on behalf of both Authors, thanked the Fellows for their kind reception of the paper. In reply to the President, he stated that, while aware of the wide distribution of Red Chalk over the district, it was to its association with bored pebbles of hard white Chalk and bored shells of *Gryphæa* that the Authors attached importance. This association appeared to be confined to the eastern and southern parts of the district. With regard to the method of distribution of erratics, the Authors, although not fanatical upholders of the land-ice theory, had been led by the facts to adopt this view in their conclusions. Attention had been paid to the possibility of derivation of material from the sea-floor, as suggested by Mr. Lamplugh. Owing to the lateness of the hour, he was unable to deal fully with the points raised by other speakers.

17. *On* Overthrusts *at* Tintagel (North Cornwall).[1] By Henry Dewey, F.G.S. (Read April 7th, 1909.)

[Plate XIII—Map.]

Contents.

I. Introduction.

On mapping the country to the north of Bodmin Moor for the Geological Survey, it was found that the slate-rocks, as noted by Mr. John Parkinson, are separable into several well-marked lithological types. These types are of widespread occurrence, and strike across the country in parallel zones in a general west-north-westerly and east-south-easterly direction with a constant dip to the north-north-east.

But, although this stratigraphical succession occurs over so wide an area, it apparently broke down in the Tintagel district, where a repetition of the strata was found near the coast. Subsequent investigation, however, proved the repetition to be due to overthrusts from the west-north-west. With the district affected by overthrusts I propose to deal in the present paper.

Several observers have written about the geology of Tintagel, but as none of them interpreted the structure, it is only necessary to give references to their papers in the following list:—

H. S. Boase, Trans. Roy. Geol. Soc. Cornwall, vol. iv (1832) p. 166.

A. Sedgwick & Sir R. I. Murchison, Trans. Geol. Soc. ser. 2, vol. v, pt. iii (1840) pp. 672–713.

A. Sedgwick, Quart. Journ. Geol. Soc. vol. viii (1852) p. 1.

David Williams, Trans. Roy. Geol. Soc. Cornwall, vol. vi (1846) p. 122.

Sir H. T. de la Beche, 'Report on the Geology of Cornwall, Devon, & West Somerset' 1839, pp. 56–58.

D. Sharpe, Quart. Journ. Geol. Soc. vol. iii (1847) p. 74.

S. R. Pattison, Trans. Roy. Geol. Soc. Cornwall, vol. vii (1865) p. 3.

W. M. Hutchings, Geol. Mag. dec. iii, vol. vi (1889) pp. 53, 101 & 214.

J. Parkinson, Quart. Journ. Geol. Soc. vol. lix (1903) pp. 408–28.

II. Description of the Area covered by the Map (Pl. XIII).

The area represented on the map covers about 5 square miles, with about 4 miles of coast-line. The district forms a plateau ending off in cliffs which are between 300 and 400 feet high. A portion of

[1] Communicated by permission of the Director of H.M. Geological Survey.

a still higher plateau rising to 600 feet occurs in the south-eastern corner of the map. Two small streams dissect the lower plateau, the one on the north forming the Rocky Valley; and the other, on the west, the Trevena Valley. The whole area forms a land-mass which protrudes from the general coast-trend of North Cornwall, and from this mass several smaller headlands jut out westwards.

The order of succession of the rocks is as follows:—

(vi) The Tredorn Phyllites.
(v) The Trambley Cove Beds.
(iv) The Volcanic Series.
(iii) The Barras Nose Beds.
(ii) The Woolgarden Phyllites.
(i) The Delabole Slates.

Epidiorites (intrusive into all the above).

(i) The Delabole Slates.

These slates are mainly composed of matted flakes of sericite with some chlorite, pyrite, and ilmenite, and garnets are plentiful. Small grains of zircon are apparently the only clastic minerals in the rock. The beds can best be studied in the great quarry at Delabole, about 5 miles to the south-east of Tintagel. Here two varieties are seen: one is grey-blue in colour, and furnishes the well-known roofing-slate; the other is grey-green, and is rejected in the process of working. The two kinds of rock are local variations of, and pass by insensible gradations into, one another. The grey-blue slate was described and analysed by J. A. Phillips [1] and other workers.

Certain bands in the quarry contain fossils in abundance, the best known fossil being the so-called 'Delabole butterfly' (*Spirifer verneuili*).

The grey-green beds are less well cleaved than the grey-blue; they are often spotted with oval white patches, and at times by rusty iron-ore spots. Flakes of micaceous pyrite, weathering into brown circular zones, spot the typical grey-blue slates, and the spotting is a valuable aid to their recognition in the field. Both varieties occur in the Lanterdan and other quarries marked on the map.

(ii) The Woolgarden Phyllites.

These beds vary slightly from place to place, but by far the most usual form is a banded phyllite. The banding is seen on cross-fracture to be due to alternating layers of gritty and chloritic or sericitic material. The sericitic variety is usually seen, and has a crystalline, saccharoidal appearance; but the chloritic variety is in places developed to the exclusion of the sericitic one. Another feature which distinguishes this phyllite is the constant presence of a secondary green mineral, which at times can be identified as ottrelite and at others as clinochlore.

[1] Quart. Journ. Geol. Soc. vol. xxxi (1875) p. 319.

The ottrelite-phyllites of Tintagel were described by Mr. W. M. Hutchings,[1] and this was the first record of the occurrence of ottrelite in British rocks. Mr. J. Parkinson [2] carefully described a somewhat similar rock from Davidstow, but identified the secondary mineral as clinochlore. These two minerals, however, do not alone 'spot' the phyllites; for another mineral, which agrees neither physically nor optically with any described chlorite or chloritoid, is very abundant in rocks from widely separated localities.

The three kinds of mineral, nevertheless, resemble one another very closely, and their presence on the surface of the phyllites renders the identification of the rock in which they occur easy in the field. Although the cleavage is poor, the rock constitutes the best building-stone in the district, and it is largely quarried.

At Woolgarden Farm, St. Clether (off the map), this phyllite is especially well exposed; but the rocks are also well exposed at Bossiney, near Gillow Quarry, and north of Lanterdan Quarry, where their characters may be studied.

(iii) The Barras Nose Beds.

These consist, for the most part, of blue-black gritty slates. Under the microscope they are seen to be almost wholly siliceous; but they also contain strands of chlorite and much carbonaceous matter. On cross-fracture well-marked black and white banding occurs. The rock is hard and brittle. In many coast-localities pressure has produced intense brecciation, and in such cases the breccia is cemented and veined with infiltrated quartz.

Tourmaline-needles are characteristic of many of the specimens, especially of those from the south side of Gullastem.

Barras Nose is practically built up of these thin gritty slates, which lie bare on the slopes of the headland so as to be easily studied.

(iv) The Volcanic Series.

Above the Barras Nose Beds a great thickness of sheared lavas dip northwards. Their distribution is seen on the map (Pl. XIII). From their present condition it is difficult to say what was their original constitution, but some indication is obtained from less-sheared examples; those occurring at Trebarwith Strand in the south of the map may be taken as examples. At this locality, they are vesicular pillow-lavas very rich in calcite.[3]

Usually, the rock is in the condition of a green or purple schist composed of chlorite or actinolite. Porphyritic felspars are preserved in some cases, particularly well seen near Treglasta in Davidstow,

1 Geol. Mag. dec. iii, vol. vi (1889) p. 214.

2 Quart. Journ. Geol. Soc. vol. lix (1903) pp. 408–28.

3 It is probable that these lavas are part of the same sheet as that occurring at Portquin Bay and neighbourhood, described by Mr. Reid and myself in this Journal, vol. lxiv (1908) pp. 264–69.

Fig. 1.—*Section from the coast at West Quarry, through Treknow Valley to Trewarmett Lane, on the scale of 6 inches to the mile.*

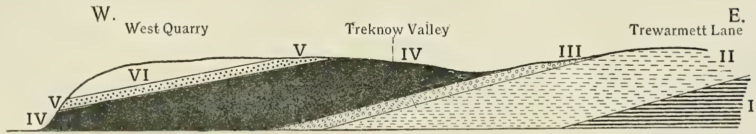
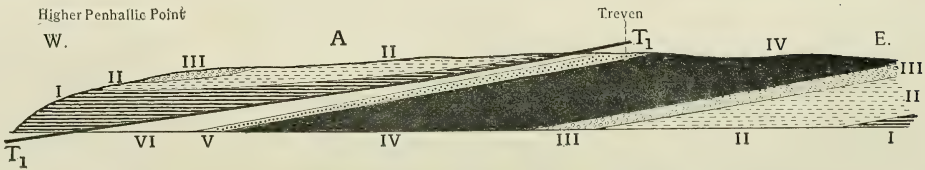


Fig. 2.—*Section from Higher Penhallic Point, through Treven, on the scale of 6 inches to the mile.*



outside the map. Types rich in epidote are widely distributed, and are common at Gullastem and Trevena. Some of the lava is so rich in calcite that it was burnt for lime, but the tendency of the rock to run to a slag rendered the practice risky, and it was discontinued.

At Tintagel Haven the lavas are rich in secondary silica, and the felspars (although showing strain-shadows) are large and well preserved. The original ferromagnesian constituents have in all cases been converted into chlorite and actinolite, and this conversion occurred after the shearing.

Magnetite is the chief iron-ore; but pyrite is not uncommon, and sagenitic rutile is often visible.

(v) The Trambley Cove Beds.

These resemble the Barras Nose Beds in many respects, and do not require description. It may be noted that, in inland localities, poorly preserved fossils occasionally are found in these slates.

(vi) The Tredorn Phyllites.

These phyllites vary slightly in colour, but are usually grey-green. They consist mainly of chlorite and sericite, and often contain small white felspars scattered through the meshes of the rock-substance. This type is common in the west, and is replaced inland by grey-green softer phyllites. Cleavage is not usually well developed, though the rock was quarried at several places for slates. Fossils of Upper Devonian age are abundant in some bands, but are seldom specifically determinable: *Spirifer verneuili*, *Fenestella*, and crinoids are the common forms. The phyllites are best seen at Trevalga cliffs, in the north-eastern corner of the map (Pl. XIII).

Besides these rocks, bosses of epidiorite occur intruding into all the series described.

III. Structure of the District.

Having described the rocks, we may now return to the map. The general strike over the greater part of the area represented is north-north-east and south-south-west; but Bossiney Bay marks the position where an abrupt change of strike occurs. From the coast at Trevalga, for over 12 miles inland, the rocks strike south-south-eastwards.

The structure of the district will be best understood by studying the map and sections. Beginning at the south-eastern corner of the map, and following the line of section (fig. 1, p. 268), we note that the sequence is perfectly normal. Along the line of section illustrated in fig. 2 (p. 268) the succession is regular to the top of the Tredorn phyllites. Overlying these, we find (i) the Delabole Slates; (ii) the Woolgarden Phyllites; and (iii) the Barras Nose Beds. The section shows that the Barras Nose Beds form a mere

Fig. 3.—*Section from Tintagel Island across Trevena Valley, on the scale of 6 inches to the mile.*

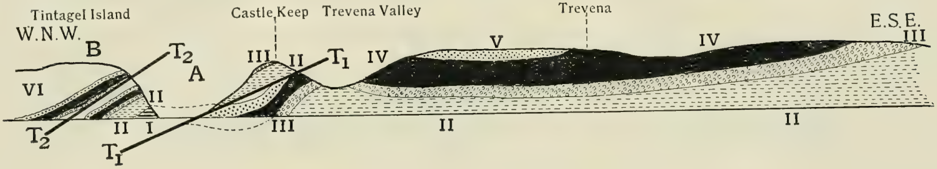
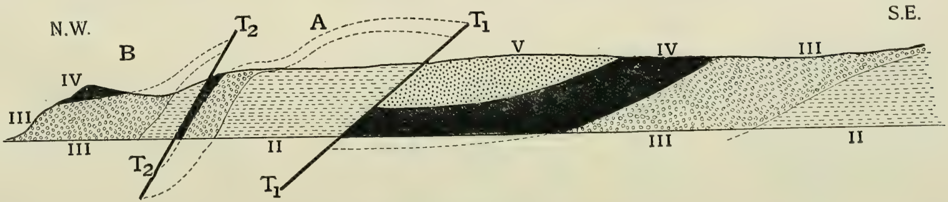


Fig. 4.—*Section from Barras Nose through Trevena Valley, on the scale of 6 inches to the mile.*



capping at the top of the cliff, and that as the cliff descends to the sea the underlying Woolgarden Phyllites reappear in its face, followed by the Delabole Slates, which compose the rest of the cliff to below sea-level. That is to say, one meets with a repetition of the beds on walking from east to west, with lower beds lying above the higher. This disposition of the beds could only have been brought about by overthrusting (T_1).

Folding would have caused the beds to crop out in either of the following orders:—Beds 4, 3, 2, 1, 2, 3, 4, in the case of an anticline; or Beds 1, 2, 3, 4, 3, 2, 1 in the case of a syncline. The repetition shown in the section is Beds 1, 2, 3, 4, 5, 6, 1, 2, 3, an order of succession which could only have resulted from overthrusting. South of this section the higher beds are not found; but, as seen in the next section (fig. 3, p. 270), the higher beds of the series appear at Tintagel. In this section the sequence is again normal as far east as the Castle Keep; but the beds are folded into a syncline and anticline. At the Keep a repetition of the lower beds commences, and we find the Woolgarden Phyllites and the Barras Nose Beds overlying the upper beds of the series. The section also shows the volcanic rock at the base of the cliff below the Keep, and the higher members of the series in the cliff-face. The left side of the section shows the structure of Tintagel Island (see also fig. 5, p. 274). On the south-eastern coast of the Island all the beds of the series are seen in the cliff-face, and the lower beds can be easily recognized as the continuation of the lower beds at the Castle Keep: that is, they form part of the overthrust mass (T_1). The section, however, shows a second repetition of the beds, about half way along the southern cliff of the Island. These beds, although inaccessible in the cliff, are recognizable by their colours from a distance, and some of the beds can be examined on the Island (see p. 273). There is, consequently, evidence of two overthrust masses; and, for simplicity, these will be lettered A and B.

Turning to the fourth section (fig. 4, p. 270), the normal sequence is again seen on the east, succeeded by (ii) the Woolgarden Phyllites, (iii) the Barras Nose Beds, and (iv) the volcanic rocks of the overthrust mass, A. At Barras Nose (see fig. 6, p. 276), the second overthrust mass, B, is admirably exposed (see p. 275). Here again the argument applied to account for the first repetition of beds holds good; namely, that the second repetition is due to overthrusting.

These four sections are drawn approximately at right angles to the strike of the beds, and fail to bring out the hade of the thrust-planes. This is indicated on the map, where it will be observed that on the south, only the lowest bed of the overthrust mass is found; but, as we proceed northwards, the higher beds of the series come to the surface. Thus, at Lanterdan Quarry, only the lowest bed is found; at Dria Quarry the Woolgarden Phyllites, and at Lambshouse Quarry the Barras Nose Beds are exposed; while at Tintagel all the beds occur. It is obvious that this disposition

of the beds at the surface is due to the north-westerly hade of the thrust-planes. As shown on the map (Pl. XIII), the great anticline in which the beds of the normal sequence are folded pitches north-westwards, and produces a similar effect to that produced by the hade of the thrust-planes (T_1 & T_2) in bringing to the surface the lower beds towards the south-east of the area shown in the map.

IV. The Coast-Sections.

Trebarwith Valley and Cliffs.

Trebarwith Strand, in the southern part of the map, is a popular resort, and is easily reached by a road from Camelford Station. This road is called the Sanding Road, and between the station and the sea it crosses all the rock-types dealt with in the present paper, following a valley in which excellent sections are exposed. On the east the basset-edges and crags are composed of Delabole Slate and its varieties. This slate was quarried at the numerous great quarries on each side of the road, and these supply fine material for study of the rock. Near Trewarmett Bridge the Woolgarden Phyllites appear, and extend westwards for some distance, at first interfolded with the Delabole Slate, but afterwards alone. By the lane leading to Trebarwith Village the Barras Nose Beds are seen; and in the lane north of the valley, running between the Mill and Tintagel, the slaty rock was quarried. Beyond this place the picturesque craggy rocks of Treknow Valley belong to the Volcanic Series.

Above these beds the Trambley Cove and Tredorn Beds are found. It is difficult to describe exactly their distribution; but, in general, it may be explained that the tops of the hills and cliffs between Treknow Valley and the sea are composed of Tredorn Phyllites. The same phyllites also occur on the top of Dennis Point and run down to Treligga. Below them lie the blue-black slates (Trambley Cove Beds), which are also exposed in the lane leading from Trebarwith Strand to Treknow, and in Port William Bay by the roadside and on the foreshore.

Over this area the beds dip to the west by south, so that they appear both inland and in the cliff-face. In walking along Trebarwith Strand the cliff-face can be studied, and the volcanic rocks which constitute the foreshore are seen in the cliff-face covered by the Trambley Cove Beds, while the Tredorn Beds compose the cliff-top. The succession continues as far as Lanterdan, where the overthrust Delabole Slates occur as seen in fig. 2 (p. 268) and described on p. 269. Concentric bands of vesicles filled with calcite reveal the pillow-forms in the volcanic rocks at Trebarwith Strand, and at Vean Hole several shear-lenticles appear at the top of the Trambley Cove Beds. Penhallic Point is the best place to view the whole cliff-range, and from here the marked change caused by the differing hardness of the beds is pronounced.

The Tintagel Cliffs.

Northwards of Lower Penhallic Point the cliffs are mainly of Delabole Slates; but the Woolgarden Phyllites (with ottrelite) occur at the top, with patches of Barras Nose Beds near Lambshouse Quarry and the Church.

The volcanic rock is seen at Hole Beach; it is cut off by a fault, disappears for nearly a mile, and reappears on the foreshore about a quarter of a mile south of Tintagel Island. At Trebarwith its top is over 200 feet above the sea; but the mass declines to the north and disappears beneath the surface, then curving upwards and reappearing near Gillow Quarry. An interesting fact, as proving its underground extension, is that the lava was found 50 feet below the sea in a borehole at Lambshouse Quarry, midway between Hole Beach and Tintagel.

Tintagel Island.

It is difficult to describe the complicated geology of the Island, but a good deal of it may be seen from the cliffs in front of Tintagel Church. The steep southern cliff of the Island is crossed by bands of rock of different colours representing difference of composition. Two prominent blue-black bands are separated by a greenish zone; while silvery slate and phyllites both overlie and underlie these beds. About half way along the southern cliff of the Island (fig. 5, p. 274), these bands are interrupted near a cave, and a repetition of the same rocks occurs. From the view (fig. 5) and from the section fig. 3 (p. 270) the position of the bands will be seen. In order to study them, it is necessary to follow the path leading to the Castle gateway. At the bottom of the path are grey-green phyllites of ill-defined characters, probably the Woolgarden Beds; near the bottom of the steps the Barras Nose Beds appear, covered by the volcanic rocks. The steps, as far as their last bend to the right, are cut in the volcanic rocks; at the bend the Trambley Cove Beds (Upper Blue-Black Slates) appear, and compose the cliff by the Castle gateway. Just inside the gateway the Tredorn Phyllites occur above the Trambley Cove Beds, but beyond the Castle wall the lava is again seen. Nearly all the top of the Island is Tredorn Phyllite. Another view of the two series of rocks in the eastern cliff of the Island is seen from Tintagel Haven. If a descent is made to the south side of the neck of land joining the Island to the mainland, the first rocks to attract attention are the volcanics at the base of the cliffs in front of the Keep. These are normally overlain by the Trambley Cove Beds and the Tredorn Beds; while the Delabole Slates occur in the old quarries. Another prominent feature is the great slickensided fault-face beneath the Keep, and a little to the south are two smaller faults along which the sea has worn caves. In these caves fine stalagmites and calcitic encrustations may be seen.

Immediately below the wall of the Keep the Barras Nose Beds

Fig. 5.—*Tintagel Island, seen from the south-east.*

[The view shows the thrust-plane T_2 and the overthrust masses A and B. The thrust (T_1) not shown, runs along the steep cliff on the right of the photograph.]

attract attention by the contrast between their deep blue-black colour and the pale silvery green of the Woolgarden Phyllites beneath them. In the entrance to the Keep they are seen to be sheared into numerous shear-lenticles, filled with broken greenish rock and vein-quartz.

Tintagel Haven and Barras Nose.

(See figs. 4 & 6, pp. 270 & 276.)

The two series of beds seen in the eastern cliff of the Island reappear at Barras Nose, and in a little ridge of rock from which a boat is suspended on davits. Barras Nose is for the most part made up of blue-black slate (Barras Nose Beds), often gritty, overlain by typical sheared volcanic rock. The crag at the top of the headland contains a band of sheared quartzitic and calcitic rock, banded with veins of very pure magnetite crystallized in octahedra. This rich band of iron-ore is, unfortunately, not extensive enough to work: if it were of more widespread occurrence, it would form a valuable ore. Similar magnetiferous bands of rock are seen in Treknow Valley. On the south-east side of Barras Nose there is an escarpment of the silvery-green Woolgarden Phyllites, underlain by a second band of lava. This second band continues along the top of the little ridge from where the boat hangs (see fig. 6). This ridge, however, is not entirely composed of volcanic rock, for the Barras Nose Beds form the mainland side of it. The same blue-black slate underlies the lava in the escarpment, and is also found in front of the Hotel.

The structure of Tintagel Haven is very complicated; but the Woolgarden Phyllites certainly occur near the Tea-Rooms. Under the Waterfall, Mr. W. M. Hutchings[1] found the volcanic rock; but the section was hidden by beach in 1908. This rock is a continuation of that seen at the bottom of the cliff below the Keep.

Inland the Woolgarden Phyllites occur east of the Hotel, and form the uppermost part of Smith's Cliff. Bosses of epidiorite have intruded into them at several localities along this cliff. At the base of Smith's Cliff the lava reappears, including two 5-foot bands of blue-black slate.

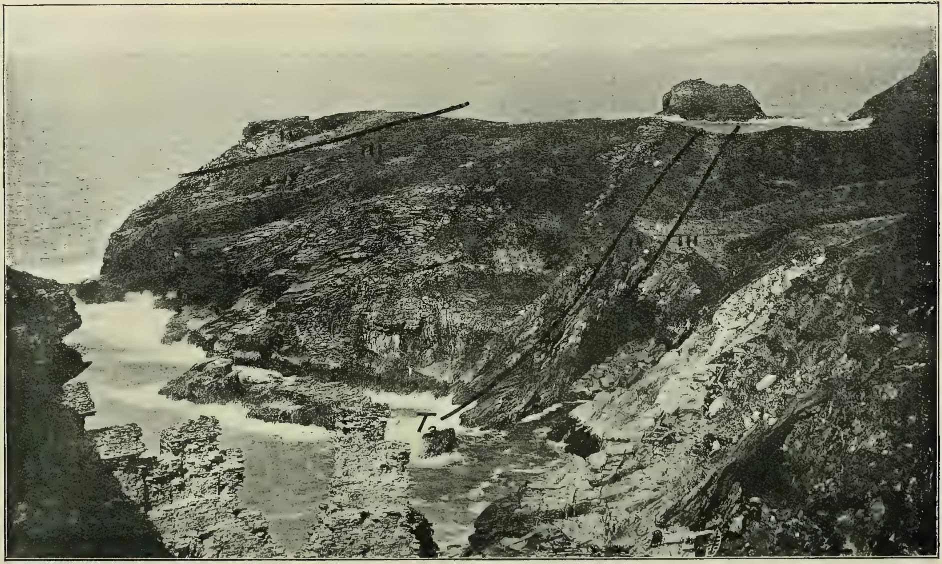
A small bay separating Smith's Cliff from Willapark is bounded by steep cliffs entirely made up of lava; the blue-black slate overlies the lava at Willapark and Smith's Cliff, and at the former place the Tredorn Beds form the headland. Lye Rock and the Bossiney Sisters also consist of the Tredorn Phyllites.

Bossiney Bay.

All the upper beds which formed the nose of the anticline have been eroded away by the sea at this locality, and the Woolgarden Phyllites occupy the range of magnificent cliffs between Trewethet Gut and the Elephant Rock. At no other part of this coast are

[1] Geol. Mag. dec. iii, vol. vi (1889) pp. 53 & 101.

Fig. 6.—*Barras Nose, seen from the south-west.*



[The picture represents the mass B lying on the mass A, with the thrust (T_2) between them. The base of Series IV is shown by thick lines, so as to indicate the amount of displacement produced by the thrust.]

there beds so low in the series as are here exposed. West of the Elephant Rock the Barras Nose Beds and volcanic rocks compose the cliffs, and they are succeeded by the Trambley Cove Beds and Tredorn Phyllites of Willapark and Lye Rock. North of the bay, along the Trevalga cliffs, the same sequence is found. Inland excellent sections of the Woolgarden Phyllites are supplied by the numerous crags of bare rock in the Rocky Valley and St. Nectan's Kieve (east of and off the map, Pl. XIII).

Trevena Valley.

The beds occurring in Trevena Valley have been partly described in the account of fig. 3 (p. 270); but no localities were mentioned where the several types can be studied.

Most of Trevena village is erected upon volcanic rocks, which are exposed in the cuttings beside the road to the Vicarage. Opposite the Vicarage gateway a wall is built, partly on volcanic and partly on the overlying Trambley Cove Beds, and a small cliff of Trambley Cove Beds runs through the Vicarage garden.

The road leading from the village to the sea-road is flanked on the north by lava and Trambley Cove Beds; and their junction may also be seen in a yard behind the last house but one of the village, where the Hotel road turns off to the right.

The valley between the Stepping Stones and Castle Cottage is cut through the volcanic rock, Barras Nose Beds, and Woolgarden Phyllite, and the prominent ridge caused by the hard gritty Barras Nose Beds can be traced from the Stepping Stones to the Hotel stables on the eastern side and to near the Keep on the western side of the valley.

The syncline and anticline of this valley have been described on p. 271.

Trevalga Cliffs.

Little need be said of these cliffs, as the succession of rocks is normal, and constitutes the seaward termination of the main development of the beds. The different degrees of hardness of the rocks are accountable for the varied scenery of this piece of coast. From Trewethet the precipitous cliffs of lava terminate at Trambley Cove, where blue-black slates overlie the lava and form the ridge of islets known as Saddle Rocks. North of the Saddle Rocks, Long Island stands out as a pyramidal mass, while Short Island and Grower reveal the tendency of the Tredorn Phyllites to weather along joints into sea-stacks. Veins of quartz and albite-felspar traverse the Tredorn Beds at Fire Beacon, and beautiful specimens can here be collected. Fossils, chiefly *Spirifer verneuili*, are also common at this locality. Looking southwards from Trewethet Gut the cliffs of Woolgarden Phyllites and Barras Nose Beds are seen, and a vein of quartz and schorl here cuts across the strike of the beds. This locality is over 5 miles distant from the Bodmin Moor Granite.

V. Tectonics of the District.

We are now in a position to discuss the causes which gave rise to the structures shown in the sections and map (Pl. XIII). We have seen that the disposition of the beds is due to an anticline which pitches north-westwards, and that this structure continues towards the east for a distance of at least 12 miles. It has been further seen that buckling occurred to the south of the nose of this anticline, and produced minor folds which increase in amplitude north-westwards, until they are replaced by overthrusts.

But it may be asked whether there is evidence in the rocks themselves of pressure sufficiently great to produce these folds. There is plenty of evidence that great pressure affected the rock-masses; and, without going into details, it may be pointed out that the Barras Nose and Trambley Cove Beds are intensely brecciated; that the lava often includes shear-lenticles; and that the phyllites are frequently in a structureless state. Under the microscope the rocks seldom contain unbroken minerals, but exhibit long, curving, parallel bands of chlorite and actinolite, enclosing 'eyes' of harder minerals.

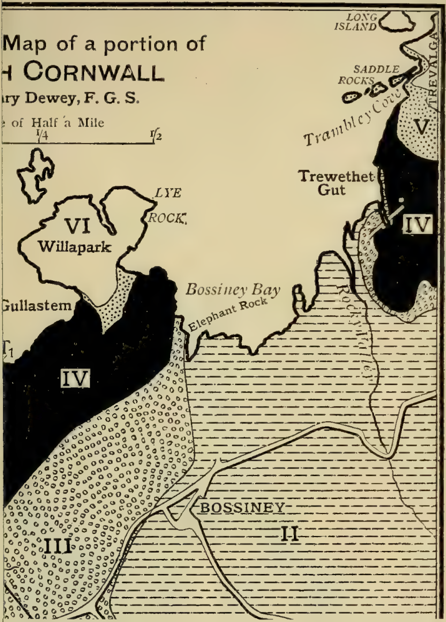
All of the rocks are contact-altered, and contain secondary minerals: the secondary minerals of commonest occurrence being ottrelite and chloritoid, white and brown micas, and actinolite. Sericitization occurred before the development of the ottrelite and white micas. Later than these are minerals of pneumatolytic origin, which occur in veins cutting across the strike of the beds at several localities, as at Trewethet Gut, where schorl and quartz-veins are exposed.

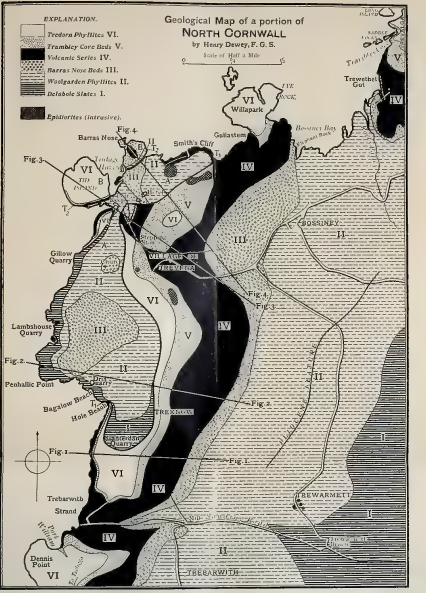
The question arises as to how this contact-alteration was effected. There is no exposure of granite nearer than the Bodmin Moor mass, which is 5 miles away; but it is possible that an underground spur of this granite-mass runs in a general north-westerly direction beneath the metamorphosed area, at a depth of about 2000 feet,[1] and produced the metamorphism of the overlying rocks.

Briefly to recapitulate this part of this paper, it may be said that sediments and contemporaneous igneous rocks of Upper Devonian age were folded into an anticline pitching north-westwards; that the beds were crumpled on the south side of the nose of this fold; that the crumpling increased in amplitude, until overthrusts replaced the minor folds towards the north-west of the crumpled area; and that denudation and erosion have since revealed these structures in the Tintagel district.

I should here like to acknowledge the kind assistance which I have received from Dr. Teall and Mr. Clement Reid. They have

[1] Clement Reid, 'Geology of the Land's End District' Mem. Geol. Surv. 1907, p. 8.


Map of a portion of
H CORNWALL
ry Dewey, F. G. S.
of Half a Mile
1/4
1/2
LONG ISLAND
SADDLE ROCKS
TREVALGA
Trambley Cove
V
Trewethet Gut
IV
LYE ROCK
VI
Willapark
Bossiney Bay
Elephant Rock
Gullastem
IV
BOSSINEY
II
III


Geological Map of a portion of
NORTH CORNWALL
by Henry Dewey, F. G. S.
Scale of Half a Mile
EXPLANATION.
Tredora Phyllites VI.
Trambley Cove Beds V.
Volcanic Series IV.
Barras Nose Beds III.
Woolgarden Phyllites II.
Delabole Slates I.
Epidiorites (intrusive).
Barras Nose
Smith's Cliff
Gullastem
Willapark
Trewethet Gut
Bossiney Bay
Elephant Rock
BOSSINEY
Gillow Quarry
VILLAGE
TREVENA
Lambshouse Quarry
Penhallic Point
Bagalow Beach
Hole Beach
TREKNOW
Trebarwith Strand
TREWARMETT
Dennis Point
TREBARWITH
Fig. 1
Fig. 2
Fig. 3
Fig. 4

helped me with many valuable suggestions, and encouraged me to continue the work that I had commenced. Mr. George Barrow has also kindly assisted me; and I wish to thank Mr. Maynard Hutchings and Mr. John Parkinson for their ready loan of microscope-slides of the rocks of the district.

EXPLANATION OF PLATE XIII.

Geological map of a portion of North Cornwall, on the approximate scale of 3 inches to the mile.

Discussion.

Mr. Clement Reid congratulated the Author on having worked out the structure of a very difficult area. Overthrusting in Cornwall seemed to have taken place during at least two periods—before and after the intrusion of the granite-masses. Could the Author say what was the date of the Tintagel overthrusts? The Author had shown that the cleavage had been developed prior to the granite-intrusion, for the metamorphic minerals lay on cleavage-planes. Was there any trace of metamorphism acting also on the breccia of the thrust-plane?

Mr. W. A. E. Ussher congratulated the Author on the successful working-out of an Upper Devonian district in which, contrary to his own experience in Devon and other parts of Cornwall, lithological types were sufficiently marked and persistent to show so clear a sequence of minor subdivisions that thrusts and disturbances could be traced out and their effects clearly indicated.

The Upper Devonian age of the rocks in this part of Cornwall was first claimed by him (the speaker) in 1891, in a tentative paper based on the new reading of the Devonian succession that he had successfully applied to the Torquay and Newton Abbot area.

The effects of the thrusts described by the Author, in bringing different members of a sequence into abnormal juxtaposition, emphasized the caution necessary in working out the relations of the Culm and Upper Devonian in the area between the district described in the paper and Tavistock, where the speaker had encountered during traverses appearances at variance with the general sequence manifested elsewhere.

He enquired whether the Author had found fossils in the beds above the Delabole Slates with *Spirifer verneuili*, and cited Upper Devonian Slates near Beer Ferrers and Holne Bridge near Ashburton, where *Spirifer verneuili* was met with, to the apparent exclusion of all other forms. The relative positions of these and other types of the Upper Devonian to the Lower Culm rocks had led the speaker to regard an unconformity between these groups as highly probable; and if the beds above the Delabole Slates were below the Petherwin Beds, the apparently unique occurrence of the latter might be due to concealment by unconformable overlap elsewhere.

As to the unconformable overlap of the plant-bearing Culm grits and shales on the Lower Culm and Upper Devonian, the evidence obtained by the speaker in mapping the St. Mellion outlier seemed to him to be conclusive.

In conclusion he expressed his admiration for the beautiful piece of stratigraphical work achieved by the Author.

The Author, after thanking the Fellows of the Society for their kind reception of his paper, in reply to Mr. Reid's question as to the date of the Tintagel overthrusts, said that he was unable to assign definitely a date, but considered it not improbable that it was pre-granitic. At the same time no pneumatolytic minerals had been found in the thrust-plane breccias, but only as veins of quartz and schorl cutting across the strike of the beds, as at Trewethet Gut. With regard to Mr. Ussher's question, the following fossils had been found in the Tredorn Beds—*Spirifer verneuili*, *Fenestella*, and traces of other bryozoa, which showed those beds to be of approximately the same date as the Delabole Slates.

18. Glacial Erosion *in* North Wales. By Prof. William Morris Davis, For. Corr. G.S. (Read March 24th, 1909.)

[Plate XIV—Map.]

Contents.

'Few subjects in physical geology would possess greater interest than a complete account of the denudations by which, after the disturbance of the strata, Wales assumed its present form.'—Ramsay, Mem. Geol. Surv. Great Britain, vol. iii (1866) p. 238; or, with verbal modifications, 2nd ed. (1881) p. 330.

I. The Form of Snowdon.

An excursion around Snowdon, the highest of the Welsh mountains, in September, 1907, led me to the conclusion that a large-featured, round-shouldered, full-bodied mountain of pre-Glacial time had been converted by erosion during the Glacial Period—and chiefly by glacial erosion—into the sharp-featured, hollow-chested, narrow-spurred mountain of to-day. Or, to phrase it in somewhat more

technical style, that a body of ancient slates, felsites, and volcanic ashes, greatly deformed in Palæozoic time and greatly worn down in successive cycles of Palæozoic, Mesozoic and Tertiary erosion, was reduced before the Glacial Period began to subdued mountain-form with dome-like central summit, large rounded spurs, and smooth waste-covered slopes, and with mature valleys drained by steady flowing streams which branched delicately headwards, with steepening slope, and which joined each other mouthwards in the accordant fashion that so systematically characterizes the drainage of all normally subdued mountain-masses. Also that this full-bodied mass was transformed during the Glacial Period, chiefly by the glacial excavation of valley-head cwms and by the glacial widening and deepening of the valleys themselves, into a sharp central peak, which gives forth acutely serrated ridges between wide amphitheatres: the serrated ridges changing into broad-spreading spurs as they are followed outwards: the wide amphitheatres, backed by high rocky cliffs, opening by great rock-steps to irregularly deepened trough-like valleys, with oversteepened, undissected sides, sometimes smooth, sometimes of a peculiarly roughened slope; the smaller lateral valleys hanging in strikingly discordant fashion over the floors of the larger valleys; and the streams, far from following graded courses in steady flow, frequently halting in lakes or hastening in rapids and cascades.

II. Excursions around Snowdon.

My first excursion around Snowdon was made for the most part in company with the late Joseph Lomas, F.G.S., of Birkenhead, who met me in the early morning of September 12th, 1907, when the steamship *Saxonia* reached the landing-stage at Liverpool. We started off at once, and by ferry, train and carriage, *via* Birkenhead, Chester, and Bettws-y-Coed, reached the isolated hotel of Pen-y-Gwryd, near the eastern base of Snowdon, in the afternoon. On the four days following we walked around the mountain by the valleys on the north-east, south-east, and south-west, ascended the opposed slopes on the east (the western spur of Moel Siabod) and west (the rounded summit of Mynydd Mawr) in order to secure general views of the main mountain and its great cwms, entered the cwms on the east (Cwm Dyli) and south (Cwm Llan) to gain a closer view of their structure and form, and had a run over Moel Trefan, a little farther west, to see its famous drift-cover bearing northern erratics and sea-shells. After Mr. Lomas's return home, I went up to the summit of Snowdon by the rack-railway from Llanberis, and had an admirable review from above of much that we had seen from below. Following this introduction to North Wales, it was my good fortune, as a member of the excursion conducted by Dr. Marr and Prof. Garwood, to see something of the Lake District, and then during the Centenary celebration of the Geological Society in London and the sectional adjournment to

Cambridge, to meet a number of geologists, British and foreign, of broad experience in many fields, but of varying opinions as to the efficiency of glacial erosion in mountain-sculpture, and to discuss with them, greatly to my own edification, though perhaps to their fatigue, the different phases of this interesting problem. Following the celebration a few days were spent, partly with Prof. Penck, of Berlin, in Devon and Cornwall for a purpose which will appear below; and then three field-days were given to the Snowdon district again, with headquarters at Snowdon Ranger, another isolated hotel, by Cwellyn Lake, in order to reconsider the whole problem on the ground, previous to the presentation of a general account of it to the Liverpool Geological Society the evening before sailing, and to writing an outline of this article during the homeward voyage to Boston, October 15th–25th, 1907. Such was the delay in completing the manuscript that, before it was finally ready for printing, the Snowdon district was again visited at the end of August, 1908, in company with several members of the Oxford Summer School of Geography; and a brief statement of the discussion here presented was made before Section C of the British Association at the Dublin meeting, early in September of the same year.

III. Welsh Terms, Local Place-Names, and Illustrations.

Several Welsh geographical terms are used in this paper, because they appear on the local sheets of the Ordnance Survey. One of these is cwm (pron. cūm)—essentially the equivalent of cirque in the French Alps, of kar in the German Alps, of botn in Scandinavia, of coire in the Scottish highlands (made over into corrie for use in the lowlands), and of combe, or sometimes cove, in the English Lake district—the name for the amphitheatral form of valley-heads. Other Welsh terms are crib, a sharp, steep-sided, serrated ridge, corresponding to the arête of the French Alps; moel, a smooth dome-like mountain, resembling the balds of North Carolina; afon, stream or river, with its equivalent in the Avons of England; llyn, lake (the Welsh ll having the guttural ch and the l sounds combined); and nant, vale or valley.

For the convenience of the reader, the use of little-known place-names as guides to the location of physical features is avoided as far as possible. Nearly all the local names employed are given on the accompanying outline-map (Pl. XIV), from which it will appear that the Snowdon mass, with a summit-altitude of 3560 feet (standing about 10 miles south-east of the Menai Straits, the narrow sea-arm by which Anglesey is isolated from North Wales), contains four large cwms:—on the east, Cwm Dyli (pron. Duli); on the south, Cwm Llan; on the west, Cwm Clogwyn; and on the north-west, a cwm not named on the Snowdon sheet of the Ordnance Survey, but which will here be called Cwm Dur-arddu, after a lake of that

name which it contains; also the smaller Cwm Glas, on the north-east. Between these cwms, in the order named, stretch the south-eastern, south-western, north-western, northern, and eastern spurs from the culminating summit; the northern spur is ascended by the upper part of the rack-railway from Llanberis. Furthermore, the mountain-mass as a whole is bordered by three deep valleys, to which the streams from the cwms descend. On the north-east is the valley of Llanberis, leading north-westwards from a fine col down to the two lakes, Peris and Padarn (immediately north of the map, Pl. XIV), between which are the great slate-quarries on the north and the town of Llanberis on the south; it may be noted that the upper part of this valley is called the 'pass' of Llanberis, 'pass' being used here for a stretch of several miles below the col, and not only for the col at the valley-head. On the south-east is the valley of Nant Gwynant, holding the two lakes, Gwynant and Dinas; and on the south-west is the valley of Nant Colwyn. The last two valleys join to drain southwards by Afon Glaslyn, and the town of Beddgelert (pron. Bethgel'ert) stands at their junction. On the north-west the Snowdon mass is continued by a number of moels, which fall off in height towards the Menai Straits; and these moels stand between the valley of Llanberis on the north-east and the valley of Afon Gwarfai, holding Llyn Cwellyn, on the south-west: the latter valley heading in a broadly open and flat col against the valley of Nant Colwyn, with which it stands about in line. Not far from this open col is another col at a little higher level, opening westwards to the valley of Nantlle, to which reference will be made later as a line of glacial overflow. Mynydd Mawr, a fine moel, stands immediately north of the head of Nantlle Valley and west of Llyn Cwellyn; its rounded summit, easily accessible, gives a fine view-point for the Snowdon mass.

Of the figures used in illustration of this article, figs. 22, 23, 26, 27, 28, 30, 31, and 32, are from sketches by the author; figs. 3 and 7 are diagrams based on sketches; the others are diagrams of ideal forms.

IV. Geological Structure of the Snowdon District.

When so short a time as eight days is allotted to so large a problem as the glacial sculpture of Snowdon and its neighbours, it is not to be expected that more attention should be given to questions of geological structure than would be required in identifying on the ground the chief formations described in Ramsay's famous Memoir on 'The Geology of North Wales' (1866, second edition 1881), and coloured on the 1-inch maps of the Geological Survey (Sheets 75, N.E., Ffestiniog: 78, S.E., Bangor), or that measurements of form, height, and distance should be carried beyond those given on the elaborate 1-inch (third edition) and 6-inch maps of the Ordnance Survey. Access to these standard materials while in the field was of great advantage. We enjoyed the recognition of

such larger structural features as the great Clogwyn synclinal fold (Ramsay, 1866, p. 121; 1881, p. 151) in felsites, ash-beds, and slates, finely displayed in the precipitous walls of Llanberis 'pass' (valley) about half way between the col and the first lake; the fold was first seen from the valley-bottom, and afterwards to better advantage from the mountain-railway, where the general structure of the huge series of rocks involved was well exposed in the over-steepened cliff that rises a full thousand feet on the north-east side of the valley to the gentler highland slopes of Glyder Fawr. We occasionally made out such smaller features as the double belt of *Lingula*-grits streaked with quartz-veins (Ramsay, 1866, p. 135; 1881, p. 167), which so curiously follows the bottom of Nantlle Valley for a time near its head, and then obliquely ascends its southern slope.

V. Indifference of Form to Structure.

Distinct as the chief structural features are in the side-cliffs of the valleys and in the head-walls and front steps of the cwms, a great part of the slopes is so well graded and grass-covered as to conceal structural details. We were repeatedly impressed, not only by the invisibility of the rocks in the well-rounded slopes of the bare dome-like hills and mountains, but also by the relative indifference of form to structure, as exhibited, for instance, in the highland north of Llanberis valley, where the gently undulating crest-line trends north-westwards between the summits of Glyder Fawr and Elydir Fawr, transverse to a series of steeply-dipping formations which strike north-eastwards and include felsites, ash-beds, Llandeilo Beds, greenstones, 'massive intrusives,' and Cambrian beds, as recorded on the geological map. Many other examples of the same nature that might be instanced are of importance, inasmuch as they prove that over large areas no great difference of resistance to subaërial erosion exists between the strongest and the weakest formations; that all the formations may be regarded as resistant, although some are more resistant than others. The finely-shaded sheets of the 1-inch Ordnance Survey map (third edition, sheets 106, Bangor, and 119, Snowdon) tell the same story. On the maps, and still more in the field, one must be impressed by the arbitrary distribution of the mountain-summits, the extremely irregular pattern of the spurs, and the apparently insequent arrangement of the valleys and streams:—'insequent' meaning that the streams seem to be of arbitrarily irregular courses, and neither prevailingly 'consequent' upon the initial slope of the strata (for they pay little attention to the dip of the beds or to the pitch of the synclinal troughs), nor 'subsequent' in the sense of having grown by headward erosion along belts of weak rocks; nor 'obsequent,' nor 'resequent'; but that whatever have been the controls of stream-location, they are for the most part so indefinite or so obscure as to be beyond recognition by the present

methods of stream-analysis. The peculiar indifference of topographic form to the trend of formation-boundaries is only another means of exhibiting the insequent arrangement of the valleys. The insequent stream-arrangement is, however, precisely what might be expected as the result of prolonged erosion upon a mass of complicated and generally resistant structure. Neither the ridges nor the streams exhibit any close obedience to structural control; the ridge-crests run in all directions in relation to rock-structure:—with, oblique to, or square across the strike of the rocks; the valley-lines are similarly indifferent; the cwms are opened in various formations; their head-cliffs, their floors and their front steps seem to occur about as often within a single formation as at the passage of one formation into another, and to stand across the strike of the rocks about as often as along it. This generalization will be of importance in the attempt, made on a later page, to restore in a general way the pre-Glacial forms of the Snowdon district. It is not, however, intended to assert that no relation is to be found between structure and form. A close acquaintance with the district would probably discover many minor examples of coincidence between strong structures and ridges, and between less strong structures and valleys; yet, on the whole, the Snowdon area shows these coincident relations only in a subordinate degree. It is, therefore, in strong contrast with such examples as the Jura Mountains, or still better the Pennsylvanian Appalachians, where the alternation of strong and weak formations has been absolutely dominant as a guide in the erosion of existing forms, and where geological structure is largely revealed in topographic relief. It seems, therefore, safe to look upon the Snowdon district as consisting on the whole of resistant rocks, and through such an introduction the main question of this paper may be approached.

VI. General Erosion of the Snowdon District.

There is no longer any dispute as to the conclusion that the hills and mountains of Wales are the result of long-continued erosion upon a once larger mass. The detailed evidence so forcibly presented in favour of such a conclusion by Sir Archibald Geikie in his 'Scenery of Scotland' for the Scottish Highlands may be applied with equal force in the case of the Welsh mountains, where the way was long ago made ready for it by Ramsay's great essay on the 'Denudation of South Wales' (1846). Indeed, both in Scotland and in Wales, the evidence in favour of several more or less complete cycles of erosion is so convincing, and the proof of deep denudation is so complete, that little is gained in the study of the present or of the pre-Glacial forms of either country by trying to restore the long-lost earlier forms due to deformation. One may here appropriately quote Playfair, who, in describing the coast of South-Western England, recognized that the present outline resulted from the action of 'wasting and decay' on the original

outline, and yet perceived that the changes had progressed so far that they could not be traced:

'To speak strictly, the original figure . . . . influences all the subsequent; but the farther removed from it in point of time, the less is that influence; so that . . . . for the purpose of such approximations as suit the imperfection of our knowledge, the consideration of the original figure may be wholly left out.'—'Illustrations of the Huttonian Theory of the Earth' 1802, p. 371.

It suffices, therefore, for the present to say that the mountains of Wales, as we see them to-day, are the deep-worn remnants of mountains that were once much greater than they are now: upon this there is general agreement.

When, however, we come to estimate the share that different erosive agencies have had in shaping the Welsh mountains, opinions differ widely. An earlier generation of geologists, with Ramsay as the leader and Mackintosh (1869) as the extremest exponent, attributed a great amount of erosion to the sea; Ramsay thought that a 'plain of marine denudation' had been worn and cut across the pre-existent mountains of deformation; that after the uplift of this plain, subaërial erosion excavated valleys in it: that glacial erosion at a still later period

'somewhat deepened, widened, smoothed, and striated the minor outlines of the mountains and valleys, and excavated many rock-bound lake-basins, but on a grand scale did not effect any great changes on the pre-existing larger contours of the country' (1881, p. 322);

and that the effects of erosion in post-Glacial time have been small 'simply from lack of time.' The chief post-Glacial changes are a small wasting of cliffs to form talus-slopes, and the erosion of small gorges and the deposition of small fans and deltas by the larger streams. The analogy already pointed out between Wales and the Scottish Highlands may be here extended; for, since the appearance of Ramsay's essay on denudation in Wales, the Highland glens have been repeatedly described as due chiefly to normal erosion acting on an uplifted plain of marine denudation, and as only modified in a subordinate way by later glacial erosion.

A later generation of geologists seems gradually to have given up marine erosion in favour of 'subaërial' erosion,—called normal erosion in this essay—as the agency by which the great ancient mountains of Scotland and Wales were for the most part worn down: marine erosion being nowadays appealed to—if appealed to at all—only in order to give the last touches in the work of planation. Sir Archibald Geikie's essay 'On Modern Denudation' (1868) appears to have played an important part in causing this change of opinion in Great Britain; nevertheless, explicit recognition of the sufficiency of subaërial erosion to reduce a mountain-mass to a peneplain without supplement by marine erosion is seldom found in British geological literature; and still more rarely does one find there a deliberate and thoroughgoing analysis of the consequences of this simple idea. Here one may

perhaps trace the influence of Lyell and Murchison, who, presumably because of their intense interest in stratigraphy, gave less attention than did their predecessors, Hutton and Playfair, to problems of land-sculpture, and thus unconsciously diminished the attention that might otherwise have been directed to the study of land-form under Ramsay's able leadership.

VII. Ramsay's 'Plain of Denudation.'

Whatever may be the causes that have directed the progress of geological investigation in Great Britain, it appears to be true that one may find a number of admirable studies on the stratigraphy, palæontology, and petrography of Wales, and yet that no one has in the last half-century given close examination to the details of those Welsh land-forms which led Ramsay to formulate his theory of marine denudation over sixty years ago. One must still turn to his original essay of 1846 for a description of the location, form and altitude of so much of the ancient plain of denudation as is still preserved: one looks in vain for any recent discussion of its verity, of the process and date of its origin, of its extent, of its completeness, of its unconsumed surmounting masses, of the date of its uplift, of its present altitude in different localities, of its stage of dissection in the present cycle of erosion, and of the shares that normal and glacial agencies have had in its dissection; and this, in spite of Ramsay's declaration, cited at the beginning of this essay, of the great interest that would be possessed by

'a complete account of the denudations by which, after the disturbance of the strata, Wales assumed its present form.'

For our present purpose, it is comparatively immaterial whether Ramsay's plain of denudation was of marine or of subaërial origin, although I think that the evidence now in hand points to the latter rather than to the former; but the present altitude of the plain in North Wales, the relation of the mountains to the plain, the date of its origin, and the stage of dissection that it reached in pre-Glacial time are of critical importance. Ramsay himself wrote, regarding North Wales:—

'There is indeed, on ascending a height, nothing more striking than the average flatness of the tops of many of the hills' (1866, p. 237; 1881, p. 329).

'All Wales shows this feature, from the Towey [in Carmarthenshire] to the slaty hills that flank Cader Idris and the Arans [mountains south of Snowdon] on the south and east, and even in the mountain land from Cader Idris to the Menai Straits [North-Western Wales], traces of a similar approximate uniformity of height are plain to the experienced eye, showing the relics of an old form of ground, in which deep valleys have been not rent but scooped out' (1866, p. 238; 1881, pp. 329–30).

It would appear that Ramsay clearly understood that the higher mountains of North Wales had escaped complete destruction by the agency which produced the plain; this impression is gained on reading, after a statement of the enormous denudation that

has taken place even over the mountain-summits, the following statement:—

> 'The harder rocks now stand out as rugged mountains, not because of extra rending and disturbance there, but because they have been and are more difficult to wear away' (1866, p. 237; 1881, p. 329).

Had the work of planation been done chiefly by the sea, the border of the unreduced masses should have been a sea-cliff. Had the work been done by subaërial erosion alone, there would presumably be a gradual transition from unreduced masses to the reduced plain. So far as I can learn, it is the latter case that corresponds with the present facts of upland form; and it is chiefly for this reason that the upland seems to me to deserve classification with peneplains of subaërial erosion, rather than with plains of marine denudation. It is true that Ramsay thought that in certain parts of the interior

> 'the old sea-cliffs are still quite precipitous, strongly reminding the beholder of the high old red sandstone cliffs on the east coast of South Pembrokeshire' (1846, p. 331);

but it must be remembered that this passage was written at a time when it was believed that nearly all cliffs and escarpments—even those of the Weald—were the work of the sea. Whatever the case may be in other parts of Wales, there does not seem to be any recognizable line of elevated sea-cliffs or bluffs surrounding the Snowdon district. Still, it should not be overlooked that the work of the later cycle of erosion, introduced by the broad uplift of the region, may have so far modified these critical features as to make their discrimination difficult, if not impossible, to-day: hence no definite conclusion is announced on this point. However, if probability may be taken as our guide, the upland of Wales may be treated as an uplifted and dissected peneplain of subaërial erosion. Under this interpretation, the residual mountains would be classed as monadnocks.[1] As such they must have been reduced, in a damp climate like that of Wales, to well-subdued or rounded forms by the time the large neighbouring areas of somewhat less resistant rocks were reduced to a surface of small relief, whether that surface was the work of marine or of subaërial erosion: this point will be again referred to farther on.

[1] In conversation with several English physiographers and physical geologists, I have found that they hesitate to use the term monadnock because it is 'barbarous,' or 'harsh,' or 'too long.' Such hesitation seems somewhat arbitrary, in view of the established use of such a trisyllable as 'meander,' of the recommended use of so harsh a word as 'bergschrund,' and of the frequent employment of so barbarous a term as 'nunatak.' However, I have no great attachment to monadnock, and no wish to press its claim of priority as a technical term; but, until some acceptable term is introduced and generally adopted, monadnock seems to me worth using, because it shares with steppe, atoll, tundra, moraine, bergschrund, wady, meander, nunatak, and various other current terms that have been introduced from other languages into English, the practical value of being a concise name for a definite, important, and more or less complicated geographical concept, which the English language does not express in any single word.

VIII. Date and Altitude of Ramsay's Plain.

As to the date of origin of the ancient plain, Ramsay implies that it was 'older than the New Red Sandstone' (1866, p. 236). I venture to suggest a much more recent date, such as the beginning or middle of the Tertiary Era. Geologists half a century ago seem not to have been impressed with the great duration of the later divisions of geological time: they assumed that several geological periods would be needed for the erosion of large valleys; but on this matter present opinion appears to have been reversed. For example, there is good reason to believe that since Eocene time, thousands of feet of strong and weak strata have been removed by subaërial erosion from broad areas in Arizona, and that in late Tertiary time, during and after a strong uplift of the lowland thus produced, the Colorado cañon was eroded through it. Again, there is much reason for thinking that since Cretaceous time, more than a thousand feet of Mesozoic strata have been removed by subaërial erosion from a belt of country stretching across England from north-east to south-west, and that during and after a moderate uplift of the lowland thus produced, many open valleys and broad lowlands of a second generation have been excavated in the Midlands. It is true that the Mesozoic strata of the Midlands are much weaker than the Palæozoic formations of North Wales; but if examples of the mature dissection of resistant structure in modern geological times are wanted, we need go no farther than Cornwall, where many of the valleys eroded since the planation and uplift of that district are thoroughly mature, although the date of planation is given as late Tertiary. Messrs. J. B. Hill & D. A. MacAlister have recently stated that the upland about Falmouth and Truro,

> 'devoid of craggy features, is suggestive of a plain of marine denudation that was upheaved in comparatively late geological times . . . The scenery of the area, therefore, has been mainly sculptured since the early part of the Pliocene period' (1906, p. 3);

and Mr. C. Reid & Dr. J. S. Flett have assigned a Pliocene date to

> 'a strongly marked shelf, or plane of marine denudation . . . . bearing no fixed relation to the limits of the granite' (1907, p. 70)

in the Land's End district. Mr. H. B. Woodward (1906) and Mr. A. J. Jukes-Browne (1907) give an earlier (Tertiary ?) date for the uplands of Eastern Devon. Smooth uplands of even greater altitude and of presumably earlier origin have been observed in Cornwall by Mr. G. Barrow (1908, p. 384); but they do not require consideration in the present connexion. A mid-Tertiary date for the peneplanation of the uplands of Wales is, therefore, not inconsistent with the erosion of open valleys in the uplifted peneplain after its elevation.

As to the altitude at which the uplifted plain of Wales now stands, it is difficult to secure information for the Snowdon district; but the uplands to the eastward of Bettws-y-Coed appear to have an altitude of 1000 or 1200 feet; farther south, around Builth,

where I saw the uplands in 1900, the general altitude is 1400 or 1500 feet. This would indicate that Snowdon and its high neighbours had a relief of some 2000 feet over the upland plain, and hence would fully warrant their being classed as monadnocks, as already suggested.

IX. Dissection of the Uplifted Plain.

Ramsay had a clear idea of the consequences that must follow the uplift of a plain of marine denudation. He wrote, for example:—

'In the long, gentle slope of the country from the hills on the right bank of the Teifi to the sea, we observe the effects first of the planing away of surface irregularities during an average general depression, and again of the further scooping out of valleys in this plain during a subsequent average elevation . . . the original approximate levels being reduced to a more fragmentary condition by the after denudations that scooped out their intersecting valleys' (1846, p. 330).

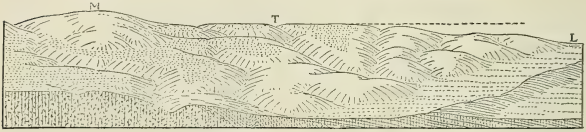
But, although the general principles involved were thus long ago recognized, their more precise application has hardly been attempted, and the degree of development of the Welsh valleys before the coming of the Ice Age has still to be investigated.

The stage reached in the dissection of the Welsh upland plain when the Glacial Period supervened is of difficult determination, so long as the amount of erosion accomplished during the Glacial Period is unknown. If it be concluded that the erosion of the Glacial Period was of small amount, then the mature forms of the valleys of to-day must be credited to pre-Glacial erosion; but, if it be believed that the erosion of the Glacial Period was of large amount, then the mature width of the existing valleys may be ascribed to glacial action, and before this action began the valleys may have been narrow. The best means that I have come upon for reaching a reasonable opinion on this matter, independent of all estimates of glacial erosion, involves the postulate that Wales and Devon-Cornwall have had—except in respect to glaciation—a similar history in modern geological times. A paragraph must be allowed for the presentation of the grounds of this postulate.

The chief reasons for regarding the modern geological history of these provinces as similar are, first, the similarity of the relation in which they stand to the Mesozoic formations which overlap them unconformably on the east; and second, the similarity of the topographic forms—apart from those of the glaciated districts of Wales—that have been developed in them. It is believed that the essential features of the two provinces in both these respects are summarized in fig. 1 (p. 292), in which the compound mass of ancient and Mesozoic rocks was reduced in a Tertiary cycle of normal erosion to a wide-spread peneplain, at the level T, surmounted by occasional monadnocks, M, and then uplifted and again dissected in a later cycle of erosion; a new peneplain, L (dotted), was then

formed on the weakest Mesozoic beds; mature or oldish valleys were opened in the less resistant rocks of the older mass, submature valleys in the more resistant rocks of the uplands (dotted), and young valleys in the most resistant rocks of the monadnocks.

Fig. 1.—*Diagram of two cycles of erosion in Devon.*



These two provinces, Wales and Devon-Cornwall, differ in area and in relief, and in the proportion and distribution of the several parts here specified; they probably differ also in a multitude of minor details; yet the general resemblance appears to hold, and upon this resemblance it seems fair to conclude that the dissection of the peneplain and its monadnocks in Wales must have been somewhat less developed in pre-Glacial times than the dissection of the peneplain and monadnocks in Devon-Cornwall is to-day. But for glaciation, Wales might be pictured as follows:—The areas of less resistant rocks would have been reduced to rolling hills in the stage of late maturity or of early old age, in which all traces of the uplifted peneplain would have been lost; the areas of more resistant rocks might still retain traces of the peneplain in the even surface of their uplands between open, early mature valleys; while the most resistant rocks would still surmount the uplands as monadnocks, and the valleys within them would have hardly reached even a submature stage in the new cycle of erosion; indeed, in their upper parts, they might not show any distinct signs of revived activity in the streams. The main valley-floors in the peripheral areas of less resistant rocks would be worn down low and open; but the headwater valleys in the most resistant rocks of the monadnocks would be little changed from the form which they had assumed in the previous cycle before uplift. Such is the stage of Devon-Cornwall to-day, and such would seem to be, but for glaciation, the present stage of development of Wales. Pre-Glacial Wales would have been in a somewhat less advanced stage of development.

X. Pre-Glacial Form of Snowdon.

It is upon grounds such as the foregoing that a tentative restoration of the pre-Glacial form of the Snowdon district is based. At the time just before the Tertiary cycle of erosion was interrupted by uplift, the then low-standing group of Welsh monadnocks presumably had well-subdued crests and ridges, only here and there

ornamented by outcropping ledges; the ridges must have been separated by fully mature valleys drained by perfectly graded, normally branching streams. Some time after the late Tertiary uplift, just before glaciers were formed upon the higher-standing monadnocks, the valleys previously eroded among them had presumably been somewhat deepened; but, if one may reason from the case of Dartmoor, the general aspect of the Welsh monadnocks must still have been that of subdued mountains, with dome-like summits and rounded spurs, drained by prevailingly graded streams of accordant levels at their junctions. Some of the larger streams of Wales may have been impelled to incise narrow gorges rather sharply in their former valley-floors, and thus in a very small way the valleys of the smaller side-streams may have come to hang over the narrow gorges cut down by the large streams. But, in the Snowdon area, there are no large trunk-rivers; all the streams are branching headwaters, and the disparity of volume among them is not sufficient to have produced striking cases of discordant junctions. The features of pre-Glacial Snowdon, as sketched in the opening paragraph of this essay, are thus justified. It would be against all reasonable analogy to believe that the sharp ridges, the steep cliffs, the valley-head cwms, and the valley-floor steps and basins of to-day could have existed at that time.

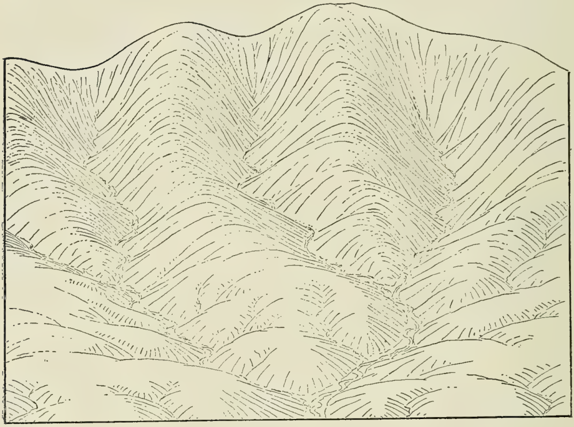
Nevertheless, if this restoration of pre-Glacial Snowdon were supported only by such inferences as have been here presented, its acceptance might not be confidently urged; but, fortunately, there are numerous rounded mountains—moels—in the Snowdon district, which are high enough not to have been overridden, like Moel Trefan, by ice from the north, and which to all appearance were never overwhelmed by the ice of the Welsh glaciers. These round-shouldered masses undoubtedly suffered some loss of size by the action of weathering, above the level of ice-work, during the Glacial Period; but this would not significantly change their form. Thus understood, the moels so well confirm the expectations of the theory set forth above, as to the summit-forms of the pre-Glacial monadnocks of the Snowdon district, that it seems reasonable to accept the expectations of theory as to pre-Glacial valley forms also.

XI. Subdued Mountains of Normal Erosion.

In order to acquire a vivid impression of the essential characteristics of normal subdued mountains with their domed summits, rounded spurs, and graded valleys, it is desirable to see actual examples of such forms, as well as to discuss the theory of their origin. For this purpose, a visit to the well-worn Appalachian mountains of North Carolina may be commended. There the long continuance of normal subaërial erosion, uninterrupted by glaciation, has reduced a great mass of deformed and resistant crystalline rocks to a late mature stage of well-rounded domes and spurs, possessing a local relief of from 2000 to 4000 feet, covered nearly

everywhere by a graded sheet of creeping, tree-covered rock-waste, and drained through an elaborately branching valley-system by well-graded streams, all of which possess that 'nice adjustment of declivities' which causes them to meet in accordant levels at the many points of junction. An attempt to show such features is presented in fig. 2 (below). It is not necessary for present purposes

Fig. 2.—*Diagram of normal subdued mountains.*



to consider the effect of renewed uplift that has been recognized in certain parts of the North Carolina mountains, because it is practically imperceptible in the headwater streams. Another pertinent example of rounded, non-glaciated mountains drained by generally graded streams with accordant junctions is found in the Cévennes of South-Eastern France. Here the stage of dissection reached in the present cycle of erosion is less advanced than that attained by the mountains of North Carolina, for some of the ridge-crests in the higher Cévennes are rather sharp, and many of the valleys are narrow-floored; nevertheless, that picturesque district affords innumerable typical illustrations of the mature stage of normal erosion in mountains of moderate relief. An area of still smaller relief, but otherwise illustrating the same principles as those so well exemplified in the mountains of North Carolina and the Cévennes, is the district of the Devon-Cornwall uplands, already mentioned; here one may see to perfection the matured accomplishment of normal erosion, not only in the perfected grades and the precisely accordant junctions of the branching streams, but also in the

graceful slopes of the soil-covered hills which rise between the streams. These delicately carved forms assure us that the graded courses and accordant junctions, which obtain throughout the branching systems of nimble water-streams, have been established no less perfectly in the innumerable down-slope lines of what may be called 'slow-creeping soil-streams.'

XII. Texture of Dissection.

In a given stage of a cycle of erosion, land forms may vary as to the texture of their dissection, or number of stream-lines crossed in a given distance. A stream-line is here understood to be a sloping line to which the converging slopes on each side contribute drainage. Such lines are very numerous if the dissected mass is of an impervious structure, yielding a fine-grained waste on a barren surface; for then every little rill will carve its minute valley, as in the Bad Lands of Nebraska, where 1000 or 2000 stream-lines may be counted in a mile. Stream-lines are, on the other hand, relatively rare, if the dissected mass is covered with a coarse and pervious sheet of creeping waste overgrown with vegetation; for here most of the rain percolates beneath the surface, instead of running off in surface-rills. The subdued mountains of North Carolina offer good illustration of a thoroughly dissected region of relatively coarse texture; here many a mile of surface has not more than ten or twenty stream-lines. Pre-Glacial Wales should be pictured as of the latter coarse-textured kind of dissection; and this picture is warranted, because the Welsh moels to-day still have large sweeping contours, seldom indented by stream-lines.

XIII. Interdependence of Parts.

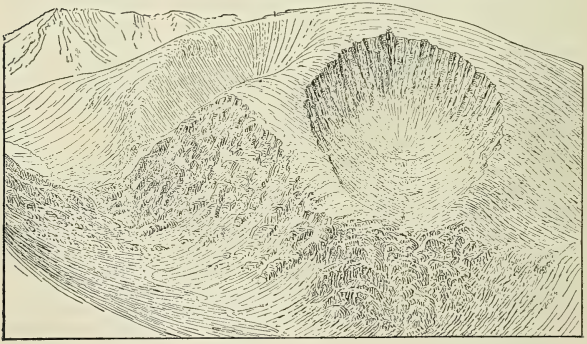
Dr. G. K. Gilbert called attention thirty years ago, in his classic report on the Henry Mountains, to the well organized interdependence that gradually comes to be established among all the elements of a normal drainage-system; an interdependence so delicately adjusted that a change in one part calls for some slight change in every other part. The later study of river-systems and of mountain-sculpture has only served to confirm Gilbert's fine generalization. When one is persuaded of the truth and pertinence of this physiographic principle, its application in such a problem as the one here in hand is highly serviceable. It is surely a practical aid, in studying the actual forms of a glaciated district like that of Snowdon, to construct as carefully and definitely as possible a mental picture of the forms that should have occurred there before the district was glaciated; and in this mental construction, it is reasonable to appeal to the forms of Dartmoor, the Cévennes, and the North Carolina mountains, as homologues of the normal forms of North Wales in its pre-Glacial stage. It is, moreover, a great encouragement to feel that the normal development of land forms

proceeds in so orderly a manner as to give assurance that, when a given stage of development is attained, a certain reasonable association of hill-and-valley forms must be produced. Irresponsible, arbitrary assumptions are thus excluded; the details of a normally carved landscape come to have an organic consistence; and every item of form has its reasonable place and significance.

XIV. Abnormal Forms of the Snowdon District.

Imagine Snowdon to be visited by an observer acquainted with mountains of normal form, and persuaded that the theory of the cycle of normal erosion (in which glacial erosion plays no part) is essentially true, but unacquainted with the forms of glaciated mountains. Such an observer would be forcibly struck by the frequent occurrence of peculiar features of which he had not previously seen examples, and for which he could give no normal explanation. The valley-heads and many of the ridges between them, the valley-sides, and the valley-floors would appear to be of abnormal form. It is true that the smoothly graded slopes of the

Fig. 3.—*Diagram of a cwm in a subdued mountain, based on a sketch of Cwm Du in Mynydd Mawr, looking southwards.*



Welsh moels would correspond, as far as they go, with portions of a normally carved mountain-group, such as ought to have been drained by a maturely organized river-system; but elsewhere the departures from normal form would seem very pronounced.

Close alongside of the graded summit and slopes of a moel, stand the head cliffs of a rock-walled cwm, that by some peculiar process has been excavated irrespective of rock-structure in one side of the dome-like mass, as in fig. 3; the cwm-head cliffs are so steep that the fall of fragments from their upper part is rapidly forming a

growing talus, by which the floor of the cwm is encroached upon. Thus the cliffs are not so steep now as they were once. It is true that valley-head ampitheatres of a somewhat cwm-like form are found in non-glaciated mountains, but they differ from typical cwms of glaciated mountains in two significant respects :—first, their heads are half-funnel shaped, rather than half-cauldron shaped: their walls are not abrupt cliffs, but are simply the steepest headwater slopes of normally branching stream-lines, under the action of which the funnel-shaped valley-head has been retrogressively excavated, as in fig. 2 (p. 294); second, each valley-head of normally carved mountains is drained by a stream of decreasing slope, while a cwm is fronted by a rock-step of increasing slope, on which the outflowing stream openly cascades to a lower level, as in fig. 3 (p. 296). The cwm is therefore evidently due to some special excavating agency that has worked much faster than the slow weathering by which the slopes of the moel have been so evenly graded, and the excavating agency is not now operative, for waste from the top of the cwm-cliffs is accumulating at their bases. It is as if the normal processes, now again in operation, were hastening to restore and regrade, but at a lower level than before, the broken arch of the mountain-dome. Cwm Du breaks the arch of Mynydd Mawr as abruptly as if it were a huge quarry; its sharp edge is hardly exaggerated in fig. 3.

Even more abnormal than the cwm-head cliffs is the rock-step by which descent is made from the cwm-floor to the broad valley into which it opens. Not enough has been made of this discordance of level in most descriptions of cwms, for it is a most extraordinary feature, the like of which is not to be seen in mountains of normal erosion. As a consequence of the discordance the branch stream, by which a flat cwm-floor is drained, descends to the wide open valley-floor of the main stream in a series of cascades which are only just beginning to cut a ravine in the main valley-side. This last point is also of importance; for, if the cwm be regarded as the work of normal erosion under the leadership of the cwm-stream, the cascades ought now to be hidden in the depths of a large gorge: but instead they usually flaunt their whitened waters on the ledges of the main valley-side, or at most they have only just begun to ensconce themselves in a cleft. This is manifestly a most abnormal relation; for, if the main valley is maturely open, every side-stream ought to enter at an accordant grade by a valley proportionate to its size. The disparity of development between the main and the side-valleys cannot be ascribed to differences of rock-resistance, as if the development of the main stream and its valley had been hastened because they followed a belt of weak rocks, while that of the side stream and its cwm had been retarded because they occurred in a belt of resistant rocks; for many cases can be pointed out where the main valley and the side cwm occur in rock of the same kind. Nor can the disparity of development be ascribed to difference of stream-volume, as might normally be the case if the main valley

were drained by a large river, and the cwm by a trickling rivulet; for a number of examples can be shown around Snowdon where the main stream is less than ten times the volume of the cascading side-stream. The main valley is therefore due to some excavating agency that deepened the valley-floor very effectually, while the deepening of the cwm-floor by the side-stream was as effectually suspended. The cwm-stream is now doing its best to cut down the floor of the cwm from which it issues; it may have already cut a little cleft from 5 to 50 feet deep into the rock-face of the main valley-side, and it will eventually bring about an accordant junction of the main valley and that of the cwm.

Some of the Snowdon cwms have a significant amount of drift on their floors; for example, the front step of Cwm Dur-arddu seems to be rather heavily drift-covered; and a drift-sheet covers the front step of the lower floor of Cwm Clogwyn near the slate-quarries; yet the bare ledges on either side of these steps are so disposed as to make it very improbable that the cwm-steps are largely built up of drift. Indeed, a remarkable feature of the Snowdon district is the small quantity of drift that is left upon it. No large moraines were seen in the valleys; and in the cwms the few moraines noticed seemed to be of less volume than the post-Glacial talus. The best cwm-moraines are those of Cwm Dur-arddu; some of these, rocky and bare, like fallen stone walls, lie close around the blue lake in the cwm-floor; others of somewhat greater age, already rounded and grassed over, lap over the southern part of the front step of this fine cwm. The difference in the age of these two sets of moraines, as indicated by the freshness of one and the grass-cover of the other, suggests that they might be referred to different epochs of the Glacial Period; if so, the only effect of the latest epoch would have been the making of a small glacier in this cwm, for nowhere else in the Snowdon group are moraines of so very fresh an appearance to be seen.

The discordant or hanging relation usually found in the Snowdon district where a main valley and a side-valley join is only an extension of the discordant relation between a cwm-floor and that of the valley to which it opens. The discordance of level between the two valleys appears to increase with the difference of their drainage-areas. These hanging valleys are entirely unlike the hanging side-valleys in a normal river-system, which (though rare) are of well-known occurrence. Normal hanging lateral valleys are found only in that very early stage of the cycle of erosion in which the main stream has entrenched itself faster than its side-streams; and in all such cases the valley of the main stream is only a narrow cleft or gorge, as in fig. 4 (p. 299). When the main river approaches and reaches grade, so that its own downward erosion is greatly retarded, the side-streams soon overtake it, and thus establish accordant junctions which are maintained through all the rest of the cycle, as in fig. 5. Even in a valley so immature as the Colorado Cañon, where the main river is large and of continuous flow, while the side-streams are

small and of intermittent flow, accordant junctions of trunk and branch prevail. All the more essentially accordant must the junctions of main and side-streams be when the main stream has not only worn down its course to grade, but has widened its valley-floor by the relatively slow process of lateral erosion; for, during the considerable interval of time required for this process, all the side-streams, even the smallest, will wear down the mouths of

Fig. 4.—*Diagram of a young main valley, with normal hanging lateral valleys.*

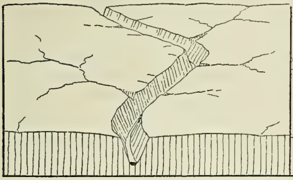
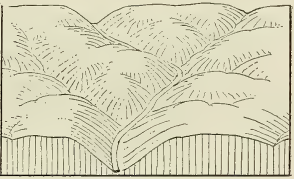


Fig. 5.—*Diagram of a mature main valley, with accordant lateral valleys.*



their valleys to as great a depth as that of the main valley. Examples attesting the truth of this principle may be counted by the hundred in the Appalachian plateau, and in any other maturely dissected non-glaciated region. The contrast of these normally accordant valley-junctions, with the discordant or hanging junctions such as prevail in the Snowdon district, is most striking.

The main valleys around Snowdon are prevailingly even-sided or trough-like; few spurs stretch into the valley-floors; and, by reason of the hanging relation of the lateral valleys, no lateral embayments are opened in the side of the main valley-floor. The cross-profile of the valleys is often a fine catenary curve, of which more will be said in a later section. A rock-step of sudden descent may occur in the floor of such a valley, as in the left side of fig. 3 (p. 296); it is sometimes dependent on, sometimes apparently independent of rock-structure. Although the valley is maturely widened, the valley-stream cascades down the face of the rock-step in a very youthful fashion. Evidently, under no normal conditions of ordinary weather and water-action can the rock-step have been made: for a cascade in the course of a normal stream is a mark of youth, and (except in special cases of hard and soft horizontal strata) is normally associated with a narrow valley-floor, hardly wider than the stream at the cascading point, and with steep valley-walls; if the valley is wide open even in the hard rocks, the cascade should normally have disappeared.

In striking contrast with the sudden increase of slope at the rock-steps is the abnormal decrease of valley-floor slope, even to the point of becoming negative or reversed, as where lake-basins occur.

Needless to say that such features are entirely wanting in subdued mountains of normal erosion. Again, in more or less close association with the rock-steps in the floors of maturely open valleys in the Snowdon district, is the occurrence of rock-cliffs in the basal slopes of the valley sides. This is all the more abnormal from the fact that the valleys are wide-floored; for, as such, their sides ought to be weathered back to a moderate declivity. The basal cliffs are not due to the undermining of a resistant stratum by a weaker stratum, such as may often occur in normally eroded mature valleys in districts of horizontal structure; for the cliffs are often in the same kind of rock as that in which the open valley itself is excavated, and in which the higher slopes above the cliffs have been weathered to grade. The steps in valley-floors and the cliffs in valley-walls in the Snowdon district are, indeed, not within reach of explanation by the ordinary processes of erosion. Again, in the immediate neighbourhood of smoothly graded waste-covered rock-slopes, the same kinds of rock may appear in very irregular bare ledges, giving the surface a highly characteristic knobby or craggy form, very suggestive of the recent action of a vigorous eroding agent (see fig. 31, p. 337).

Indeed, one may say that the general effect produced by an inspection of the Snowdon district is comparable to that caused on looking at a battered and weather-beaten statue: one may imagine that the statue has been at one time 'normally' carved by a sculptor, for certain parts of the original form may still be preserved and the rest may be reasonably inferred; but one must see also that, since its carving, it has been exposed to very different treatment, under which it has been more or less defaced. In such a case it may be possible, by restoring the proper form of the lost features, to estimate how severely the carved surface has been battered by rough treatment and pitted by the weather; and a similar possibility seems to be open in the case of Snowdon.

XV. Abnormal Forms and Normal Processes.

It may be fairly presumed that the intensity of the impression made upon the observer by what are here called the abnormal forms of the Snowdon district, will increase with the confidence that he feels in the correctness of the general theory of normal erosion, and with the strength of his conviction that a systematic distribution and succession of hill-and-valley forms must be produced during the progress of an uninterrupted normal cycle. The intensity of the impression will be all the more strengthened if the observer has gained an acquaintance with the forms of normally carved, non-glaciated mountains in various stages of erosion, but particularly in the late-mature stage of subdued form with which we are here most concerned, before he sees any glaciated mountains; for, in such a case, the abnormal features of the latter will produce something of a shock when they are first encountered. A good illustration of

this point is narrated by Mr. E. C. Andrews, of Sydney (New South Wales), who had become familiar with the forms producible in a cycle of normal erosion, from his studies in the New England district of North-Eastern Australia, and had become persuaded of the systematic sequence in their development, before he saw the intensely glaciated fiords of New Zealand, which at once impressed him as beyond explanation by normal processes (1904). My own experience was somewhat of the same kind; for, although familiar for many years with glaciated lowlands and low uplands in the northern part of the United States, my first serious studies in the Alps did not come until after I had seen the non-glaciated parts of the Appalachian system and had become convinced of the verity of a systematic sequence in the development of normally eroded forms. When, with these features and principles in mind, I saw in 1899 the hanging lateral valleys over the wide-open main valleys of the Alps, the abnormal relation stood forth as something so striking and exceptional as completely to overturn my previous opinion that glaciers were not strong erosive agents.

On the other hand, one who studies the mountains of North Wales, or other glaciated regions, without reference to non-glaciated mountains and without consideration of the theoretical aspects of normal mountain-sculpture, may very likely see nothing particularly abnormal in his field of observation, and may regard the method of discussion here adopted as unsafely based on hypothetical matter; indeed, as departing dangerously far from the safe ground of immediately observable fact. But observers who are as familiar with mountains of normal sculpture as with mountains of abnormal sculpture, and who, through extended experience in districts of different stages of development, have come to have confidence in the scheme of the regular succession of forms produced in the ideal cycle of erosion, will probably agree that, in a problem such as we have here in hand, it is highly desirable, not to say essential, to reason out the sequence of forms appropriate to normal processes, to confirm the accuracy of the reasoned sequence by appropriate observations, and to bear the confirmed sequence constantly in mind. Otherwise, when a glaciated district like that around Snowdon is under examination, there will be great danger of confusing forms of abnormal and normal origins.

It has sometimes seemed as if Ramsay's influence in this respect had not been altogether favourable; for, far from pointing to the valleys of Wales as abnormal features, he repeatedly instanced them as chiefly the work of normal erosion. He wrote :—

'By denudations, chiefly subaerial since that time [New Red Sandstone], the details of the present outlines of Wales have, I think, been produced ...... There has been plenty of time for the cutting out of valleys in old table-lands by the weather, by running water, and by glaciers' (1866, pp. 236–37; 1881, pp. 328–29);

and again :—

'By far the greater part of [that] valley excavating-work was performed between Permian and pre-glacial times ...... The work of the glaciers of the last

glacial period somewhat deepened, widened, smoothed, and striated the minor outlines of the mountains and valleys, and excavated many rock-bound lake-basins, but on a grand scale did not effect any great changes in the pre-existing larger contours of the country' (1881, p. 322).

At an earlier date Ramsay's attention was chiefly given to demonstrating that glaciers had occupied rather than eroded the valleys of Wales. Thus he wrote that in the Snowdon mass,

'six vast hollows have been scooped out by time, forming the wild upland valleys [of the cwms above-named] in some of which the signs of glacier ice are perhaps even more striking than in the Pass of Llanberis itself' (1859, pp. 424–25);

and again,

'after many a visit, I came to the doubtful inference, that a glacier probably at one time covered the whole bottom of the cwm' [Clogwyn] (1859, p. 431).

This is evidently not the language of one who regarded the cwms as chiefly the work of glacial erosion. On a later page (p. 441) a small deepening of the Pass of Llanberis by ice is implied, but throughout Ramsay's writings the measure of ice-erosion recognized around Snowdon is very small.

It should, however, be remembered that at the time of Ramsay's earlier writing it was still a question whether mountains and valleys were chiefly the result of disorderly upheavals, or whether mountains were produced by the erosion of valleys in a broadly uplifted mass. The long discussion that resulted in the establishment of the latter view for the Lake District and for the Scottish Highlands, as well as for Wales, was carried on at a time when it was hardly imagined that glaciers played a large part in valley-erosion; Ramsay himself, one of the first to recognize glaciers as important eroding agents, regarded lake-basins as their chief work. Indeed, the whole tendency of the classic discussions on mountain-sculpture by Ramsay and others has been to give the impression that the mountains and valleys of Wales and of the other rugged areas of Great Britain might be taken as types of normal mountain- and valley-forms, except for such small changes as have been produced by

'somewhat deepening, widening, smoothing, and striating the minor outlines.'

Surely an observer with this impression in mind, and at the same time unfamiliar with the forms of non-glaciated mountains and mistrustful of the theoretical discussions regarding cycles of erosion, would not find much evidence of glacial sculpture in Wales; he would have no standard normal features with which to compare the abnormal Welsh features.

Another cause that may have contributed in some degree to the same end is the prevailing absence of figures in text-books and of pictures elsewhere representing normally sculptured mountains. Such mountains are, indeed, unfamiliar forms in art; and the artist and the lover of mountains have good reason to congratulate themselves that all mountains are not of the simple, normally eroded

pattern. The smoothly rounded forms of normally subdued mountains are not inviting to painters, tourists, or photographers, who have naturally preferred the abundant detail shown in the rugged outlines, the broken slopes, the openly visible cascades and the picturesque lakes of glaciated mountains. Just as a sharp-cut gorge and not a nearly featureless peneplain is commonly, but very inappropriately, offered in illustration of the magnitude of the work of erosion, so the rugged forms of glaciated mountains are too often selected instead of the tame slopes of subdued mountains, when illustrations of the verity of mountain-sculpture are sought for, normal sculpture being tacitly implied. But, unfamiliar as the nearly featureless forms of subdued mountains may be, it is precisely such forms that must be carefully and consciously reconstructed for the Snowdon district, if one attempts to estimate by the method here suggested the amount of erosion that the Welsh mountains have suffered in their transformation from their normal pre-Glacial forms to their present highly abnormal forms.

XVI. Association of Abnormal Features with Glaciation.

The abnormal features of Snowdon and its neighbours appear to be in some close way associated with the glaciation. The cwm-floors, the valley side-slopes, the valley floor-steps are scored and striated. Similar abnormal features occur in other glaciated districts, all the world over, varying in intensity rather than in kind; but they are practically unknown in non-glaciated mountains. So persistent an association has naturally led many observers to look upon the abnormal forms as the result of glaciation: but it has been urged by other observers that the hanging attitude of lateral valleys over their main valleys, which so strikingly characterizes glaciated mountains, may be produced under normal conditions. The explanation thus offered is in essence as follows:—If a normally sculptured mountainous area, drained by mature streams with accordant junctions, be uplifted, and especially if the uplift be so disposed as to increase the slope of the chief drainage-lines, then the main rivers will be impelled quickly to deepen the main valleys, and thus the lateral valleys will be left hanging over the newly deepened floors of the main valleys. There can be no question that hanging valleys of this kind may be normally produced in the early stages of a new cycle introduced by regional uplift, particularly where the main river is much larger than its branches, and where the uplift is rapid. But such hanging valleys can endure only so long as the main river has a narrow gorge-like valley; the lateral valleys must be worn down to accordant junctions by the time the main valley-floor has become open by the lateral erosion of its graded river and by the wasting away of its walls. Hence the suggestion, that lateral valleys may remain hanging over well-open main valleys which have been deepened as a result of land-tilting, is not acceptable.

It has been mentioned above that examples of young hanging lateral valleys in normal relation to narrow young main valleys are well known, though rare, in non-glaciated regions; but it is an unbroken rule that lateral valleys and maturely open main valleys in non-glaciated regions come together at accordant levels. It would, therefore, seem hardly permissible to believe in the production of hanging lateral valleys over broadly open main valleys in glaciated mountains as a result of normal erosion, until some examples of such a hanging relation are pointed out in maturely sculptured, non-glaciated mountains. Indeed, if the association of hanging valleys with glaciated mountains is doubted, and if the occurrence of hanging valleys is explained by normal processes as above indicated, then the whole discussion is transferred from the problem of glacial action to the problem of stream-action; and as such it must be settled by the study of normally sculptured districts, not by the study of glaciated districts. No study of a non-glaciated district has yet shown it to be characterized by hanging valleys; but numerous studies attest the prevalence of accordant valley-junctions in such districts. Hence, in the entire absence of positive evidence that hanging lateral valleys are associated with wide-open main valleys in non-glaciated mountains, it seems reasonable to regard the abundant evidence as to the accordant relation of lateral and main valleys in such districts as settling the case, and to conclude that hanging valleys are (except in connexion with narrow gorges of young main rivers) to be explained in some way in connexion with glaciation.

It is, however, not so much the occurrence of any one abnormal feature, such as hanging lateral valleys, in glaciated mountains as it is the systematic combination of various abnormal features that is so strongly persuasive of the dependence of such forms in some way or other on glacial action. There is, indeed, to-day a general agreement among geologists as to the association of abnormal features, like cwms and hanging valleys, with glaciation. A study of Penck & Brückner's 'Die Alpen im Eiszeitalter' would be pertinent in this connexion. But there is still some disagreement as to the manner in which the abnormal features have been produced.

XVII. Various Methods of Discussing Glacial Erosion.

The possibility that the abnormal features of glaciated mountains might be the result of glacial erosion has been much discussed. The chief methods of discussion are as follows:—

(*a*) Observation of existing glaciers.—It has been sought to determine, by the direct observation of existing glaciers, whether the greater glaciers of the Glacial Period were effective eroding agents. Most observers have been led to the conclusion that existing glaciers slowly grind and scour the rock-surface on which they move; but some have held that the total scouring must be very small. It is, on the other hand, well known that existing

glaciers sometimes act, like rivers, as depositing agents. But there are two serious difficulties in the application of this method to the problem in hand. first, only the ends and edges of existing glaciers are accessible to observation; there the ice is thin and the pressure is small; hence the processes there observed may give no proper indication of what went on at the bottom of the enormous glaciers of the Glacial Period. Second, no one knows the duration of the Glacial Period; hence, even if the rate at which large glaciers can erode were determined, the amount of work done by the ancient glaciers would remain, under this method, indeterminate.

(*b*) Deductions from the physical properties of glaciers.—It has been sometimes attempted, by studying the physical properties of glacial ice, the rate of motion of glaciers, and so on, to determine whether glaciers can erode or not; but no generally satisfactory results have been reached in this way. Moreover, as in the previous method, the total work done could not be determined by this method so long as the duration of the Glacial Period remains unknown.

(*c*) Estimates of the volume of glacial drift.—Several attempts have been made to estimate the volume of glacial drift laid down in moraines, and thus to determine the average depth of glacial erosion of the surface whence the drift was derived. This method cannot discriminate between the drift supplied by glacial erosion proper and that supplied by superglacial weathering; and it fails to include the fine-textured drift washed forward from the moraines by streams. In any case it is inapplicable in Wales, because most of the drift from the Snowdon district is now inaccessible on the sea-bottom.

(*d*) Restoration of the pre-Glacial form of a glaciated district.—It is sometimes possible to make a rough restoration of pre-Glacial form in a district that has been glaciated. Then the difference between pre-Glacial form and present form must be equal to the glacial erosion (with the associated weathering above the ice-surface) *plus* post-Glacial changes. The latter can generally be allowed for without difficulty, and thus a useful determination of the value of glacial erosion in affecting topographic form can be gained. It was with a view to the application of this method that the preceding discussion of the pre-Glacial form of the Snowdon district was written.

(*e*) Comparison of non-glaciated and glaciated districts.—If a comparison be made between districts, otherwise similar, one of which has been glaciated while the other has not, the differences may be plausibly ascribed to glacial action. Such a comparison has been instituted in the foregoing pages. It is evident that this method should be associated with the preceding. At the same time, it must be noted that no safe conclusion can be thus reached, until it is shown that the peculiar features of glaciated mountains are such as glaciers would produce if they were eroding agents. Hence the next method must also be employed.

(*f*) Deduction of the consequences of glaciation, on the assumption that glaciers are eroding agents.—In order to learn whether the features peculiar to glaciated mountains may be reasonably ascribed to glacial erosion, it is legitimate to make the provisional assumptions that glaciers do erode and that glaciers do not erode; then to deduce the consequences of these assumptions as carefully as possible, and finally, to confront the two sets of consequences with the appropriate facts of observation. If an essential agreement is found between one set of consequences and the facts, while the other set of consequences correspondingly fails to meet the facts, it may be fairly concluded that the assumption which led to the successful consequences is correct, particularly if the two sets of consequences involve peculiar and unlike features. This method is employed in the following pages.

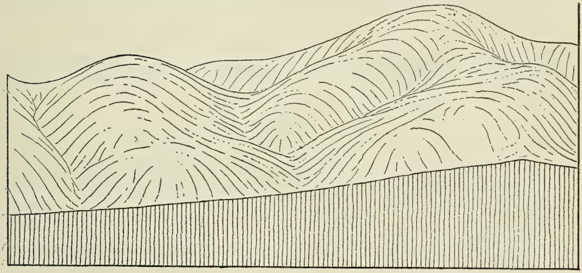
(*g*) Search for other explanations of features that are ascribed to glacial erosion.—Caution requires that all additional explanations, which have been suggested to account for the peculiar features of glaciated mountains, should be critically examined, to see whether they also are capable of producing such features. Among these explanations are: warping of normal valleys to produce lakes; faulting to produce hanging lateral valleys; revival of normal erosion by tilting, to produce hanging valleys (already considered); subglacial stream-erosion, or ordinary stream-erosion during interglacial periods, to produce over-deepened valleys; and so on. Several of these suggested explanations are considered on later pages.

The correct application of the foregoing methods ought to lead to accordant results: yet so incomplete are our observations and so divergent are our lines of discussion, that the results obtained by different investigators are notoriously unlike. The best safeguards against error are: a broad basis of observation, a careful development of inductions, a friendly consideration of every hypothesis, a logical deduction of all possible consequences from each hypothesis, a critical comparison of these consequences with the facts of observation, and a judicial decision in view of all the evidence presented. The impartial consideration of rival hypotheses is of especial importance. For this reason an effort is made in the following pages to discuss with equal thoroughness the opposed hypotheses that glaciers are effective eroding agents, and that glaciers are chiefly protective agents. The essential consequences of each hypothesis are deduced in some detail, and then with as little prejudice as possible confronted with the facts. There appears to be no safer method of procedure than this: it is the soundest method that can be employed by anyone who wishes to reach an independent opinion on this mooted question.

The first three of the above-named methods will not be further considered here. The fourth and fifth methods—restoration of

pre-Glacial form and comparison of non-glaciated and glaciated districts—have already been presented in some detail, with the conclusion that the abnormal forms of glaciated mountains are in some way associated with glaciation. It remains, therefore, to consider whether the abnormal forms of such districts, and especially of the Snowdon district, are of a kind that glaciers would produce if they were eroding agents; and, as a safeguard against error, the possibility of explaining the abnormal forms by the opposed hypothesis that glaciers are protective agents, will also be discussed. Lack of space will prevent due consideration here of certain alternative explanations; but it may be noted that all such explanations, so far as they have come to the present writer's attention, have been carefully examined, with the result of finding no explanation so competent to account for the abnormal features of a glaciated mountain-group as the one which associates them closely with glaciation.

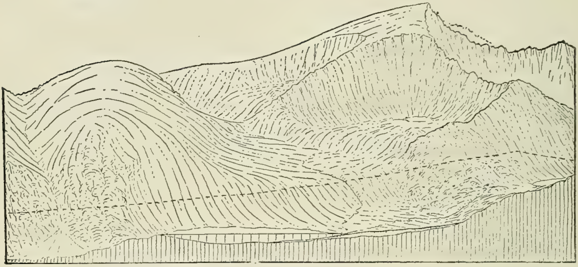
Fig. 6.—*Diagram of the pre-Glacial features of the Snowdon mass.*



It is evidently desirable, in testing the two hypotheses of the erosive and the protective action of glaciers, to begin with a reasonable conception of the land upon which glaciation takes place. It is largely on this account that the earlier pages of this essay have been devoted to the pre-Glacial history of the Snowdon district, the inferred form of which, at the beginning of the Glacial Period, is now given closer definition by means of a type-diagram (fig. 6). It is also desirable, while pursuing the discussion, to bear in mind a definite conception of the existing features of the Snowdon district: hence a type-diagram (fig. 7, p. 308) is here submitted, in which the abnormal features, previously shown separately, are compactly generalized and presented in their natural association. The problem before us is, therefore, to inquire as impartially as possible whether the transformation of a normally subdued mountain-group typified in fig. 6, to the abnormally eroded mountain-group typified in fig. 7, can be better accounted for by the supposition that glaciers are

chiefly protective, or that glaciers are actively destructive. Whatever difficulties and risks may attend this double enquiry, they will

Fig. 7.—*Diagram of the present features of the Snowdon mass, based on a sketch from the flank of Mynydd Mawr, looking eastwards.*



be lessened by following each of its two courses carefully, step by step, rather than by trying to leap at once from the beginning to the end.

XVIII. Glaciers as Protective Agencies.

Let it be assumed that small glaciers come, in an early stage of the Glacial Period, to occupy the upper valleys of a group of subdued mountains, as illustrated in fig. 8 (below). The creeping ice will

Fig. 8.—*Diagram of protective glaciers in the valleys of a subdued mountain.*

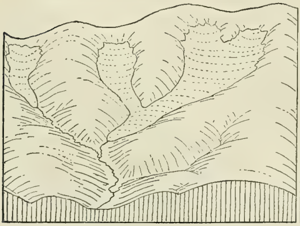
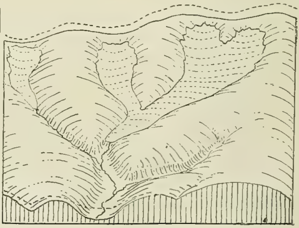


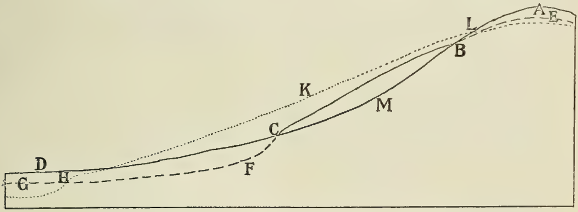
Fig. 9.—*Diagram of the effects of normal erosion on fig. 8.*



slowly scrape away the pre-Glacial rock-waste and will scour the underlying unweathered rocks into moutonnée form; then further glacial erosion is assumed to be insignificant. But, at the

same time, let it be recognized that normal erosion continues on the higher slopes above the ice, reducing them to gentler declivity; and also, farther down the valleys, deepening and widening them, as in fig. 9. In order to examine certain details, let ABMCD, fig. 10, represent a pre-Glacial stream-profile, and BC represent a short glacier; then, while normal summit-erosion changes AB to EB, and normal valley-erosion changes CD to CFG, BMC will

Fig. 10.—*Successive profiles of a protective glacier.*



remain unchanged. Several special consequences of these suppositions should be noted: First, the points B and C must stand in such relation as would represent the upper and lower ends of a glacier formed in the space between them. Second, if the lower stretch of the valley FG is to be widened as well as deepened, then the slope FG must be first worn down to grade with respect to the controlling base-level of the stream-system. Third, all the important branch streams down valley from F will develop mature branch-valleys, joining the deepened main valley at accordant level. Fourth, the distinctness of the valley-floor step (CF) will depend in great measure upon the steadiness with which the little glacier holds its end in one position. Fifth, the rock-step will have no necessary relation to rock-structure. Sixth, the more pronounced the rock-step, the more distinct should be the angle at B in the slope EBM, and the more distinct should be the corresponding angle or 'edge' along the sides of the glacier. All these consequences are illustrated in fig. 9 also, but on a smaller scale than in fig. 10.

Now let it be supposed that the glacial climate becomes more severe, so that the glacier increases in size, as shown in fig. 11 (p. 310). Its profile is shown in LKH, fig. 10. The mountain-summit above the glacier will now be worn to still gentler slopes (if the summit is not completely enveloped in a protecting névé-cover), and the valley down-stream from the glacier-end will be further widened by normal stream-action. But it cannot be significantly deepened, unless there is an elevation of the district contemporaneous with the increase in the size of the glacier; for the widening of the valley-floor in the previous stage can have taken place only after the stream had worn down its channel to

grade, and therefore no deepening can again take place (except that which slowly accompanies the wearing down of the whole mountain-mass in old age) unless the stream is revived by uplift. Such an uplift is particularly needed here as a cause of valley-deepening, because observation has abundantly shown that the extension of a glacier down its valley is usually accompanied by the aggradation of the valley-floor down-stream from the glacier with waste brought by the glacial stream; hence all the more must uplift be assumed, if glacial extension is associated with valley-deepening.

Assuming that an uplift takes place, let the deepening and widening of the chief valley go on until the form shown in fig. 12 is produced. This change will, as before, be associated with an appropriate deepening and widening of the side valleys and with the development of accordant junctions between smaller and larger streams; except in special cases where a side-glacier just reaches a side-valley mouth, as in the left front of fig. 12 (below). Additional

Fig. 11.—*Diagram showing an extension of the glaciers of fig. 9 (p. 308).*

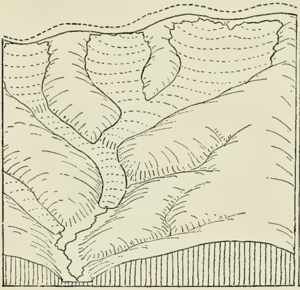
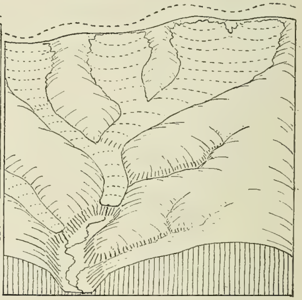


Fig. 12.—*Diagram showing the effects of normal erosion on fig. 11.*



repetitions of similar changes may take place, and finally the ice may be supposed to extend far beyond the limits of the figure during the climax of the glacial climate, protecting and preserving all the valley forms that had been produced during its successive advances.

Let the retreat of the glaciers be now considered, and let a long pause occur when they have shrunk to moderate dimensions. If the land still holds the altitude that it had gained by previous uplifts, it would follow that the production of a new rock-step at the end of the shrunken glacier will be accompanied by the more or less complete obliteration of all the rock-steps previously formed farther down the valley, and by the reduction to accordant junctions of all the hanging lateral valleys from the mouths of which

the protecting local glaciers will have retreated. Hence under the theory of the protective action of glaciers, it must be assumed that all the rock-steps in the valley-floors were made during the phase of increasing glacial conditions, unless indeed it be assumed that, during retreat, pauses occurred at the same points as during the advance, and that at each pause the land resumed the altitude which it had in the corresponding stage of glacial growth; or that no pauses occurred during the phase of retreat. The consequences of the latter supposition are illustrated in fig. 20 (p. 317), where the disappearance of the glaciers of fig. 12 reveals the valley-floor steps previously developed.

XIX. Special Features of the Theory of Glacial Proteciton.

Certain special consequences of the theory of glaciers as protective agencies need mention, particularly as applied to pre-Glacially subdued mountains.

(*a*) Protective glaciers occupying the upper parts of mature valleys in a group of monadnocks cannot produce cliffs by undercutting the valley-head slopes; the glaciers can only preserve the moderate slopes of the pre-Glacial valley-heads without significant change. The mountain-tops, in so far as they rise above the protective névé-and-ice cover, must be reduced to very dull shape during the successive episodes of glacial growth.

(*b*) Even if a glacier be protective, the water-stream that is given forth by the ice would cut back a narrow slit in the steep face of the rock-step down which it cascades below the glacier-end. The streams that are to-day rushing down such rock-steps in glaciated mountains are actively at work trenching their courses in cleft-like gorges, but they have as yet made very little progress; had the streams been there during all the long interval of time required, not only for the deepening, but also for the widening of the lower valleys, one would expect that the stream-gorges would have attained a great length and depth.

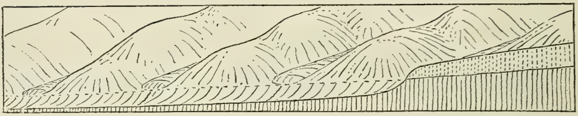
(*c*) The number of rock-steps should correspond in each of the several radiating valleys of a mountain-group like Snowdon; for each step is only the local result of a well-maintained climatic episode which must have been of essentially uniform value all around the mountain-group. Furthermore, the height and spacing of the corresponding steps should be systematically related, for each set of steps is the result of a single climatic change and of a single uplift.

(*d*) It may be noted that the necessary postulate of increasing uplift with increasing glaciation runs counter to the evidence which in many regions associates increasing glaciation with depression.

(*e*) Each enlarged portion of a valley down-stream from an ice-covered rock-step should be of normal pattern; the several side-valleys should be well opened if the main valley is well opened;

they should join the main valley at accordant levels; and the spurs that slope into the main valley between the side-valleys should be of normally subdued slope, if the main valley-floors are broad. But the normal development of accordant junctions for a group of side-valleys may be prevented by a highly specialized arrangement of side-glaciers, which shall conspire to hold their ends at the side-valley mouths, as already shown in fig. 12 (p. 310), and more clearly in fig. 13 (below). Hence, in all such cases the floors of the group

Fig. 13.—*Diagram showing the origin of hanging lateral valleys under protective glaciers.*



of hanging side-valleys must be the preserved parts of a previously eroded mature valley-system, and as such must, irrespective of the size of the side-valleys, hang at an altitude appropriate to a corresponding part of the main valley-floor preserved above the next upstream rock-step. Furthermore, (f) there can be no more groups of hanging side-valleys than there are rock-steps in the main valley-floor; and all the members of a group of hanging side-valleys must occur between two successive rock-steps in the main valley-floor. On the other hand, (g) large or small lateral valleys, not occupied to the mouth with side-glaciers, must enter the main valley at accordant level with it, and yet they may be in close neighbourhood with hanging lateral valleys.

It should also be noted that (h) the long-maintained halt of a group of side-glaciers at their valley-mouths, as required for the production of hanging side-valleys, is a much more specialized requirement of this theory than is an equally long-maintained halt of the main glacier at some unspecified point in its larger valley where a rock-step is to be made. The halt of the main glacier requires only a long-maintained uniformity of glacial climate, and while so long a halt is in itself certainly remarkable, it is not complicated by having to stand in a definite relation to any non-climatic element. The long halt of a group of side-glaciers at their valley-mouths, however, requires not only the same long-continued uniformity of climate, but the maintenance of the climate at just such a condition as shall cause a number of independent side-glaciers of unlike dimensions to end in a definite relation to a line of an altogether different quality, namely the line of the main valley to which the valleys of the side-glaciers are tributary. When it is noted that the drainage-basins of neighbouring hanging lateral valleys vary greatly in area and in altitude, it appears extremely improbable that any glacial climate could cause the

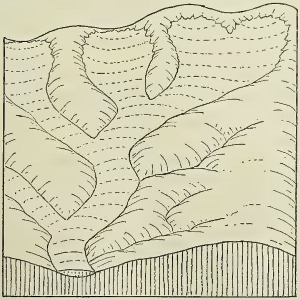
independent glaciers of such neighbouring lateral valleys to end in a line of almost uniform altitude, on which the mouths of a set of hanging valleys must, according to this theory, stand. Furthermore (*i*), the climate of the Glacial Period as a whole must, under this theory, be peculiar in advancing through several long maintained pauses to its climax, and then in moderating either with corresponding pauses or without significant pause to its close. (*j*) When the ice finally disappears, the valley-heads will be revealed, essentially unchanged from their pre-Glacial form. But certainly the most peculiar feature of the theory of glacial protection is (*k*) its fundamental postulate that glaciers do not erode, in view of the erosive action easily observed, even though slow, under the sides and ends of mountain-glaciers all the world over.

Nevertheless, if, in the face of these special and peculiar requirements, the theory that glaciers are protective should lead to consequences which correspond to observed facts, while the theory that glaciers are destructive, even if apparently simpler in requirements, should lead to consequences that are contradicted by observed facts, we should necessarily discard the second theory as inadmissible, however plausible it might have seemed at first; and we should have to accept the first theory as to all appearance competent, even though some of its requirements were such as to make it at the outset seem improbable of realization.

XX. Glaciers as Destructive Agencies.

The general discussion of glaciers as destructive agencies need not include a consideration of special stages of glacial advance, but may pass at once to the case of a well-developed glacier, as indicated in fig. 14. Erosion is assumed to take place under all parts of the glacier here shown, but the erosion may well be a slow process; the only requirement is that it should be significantly more rapid than normal erosion. It may here be pointed out that the theories of erosion under the lead of water-streams and under the lead of ice-streams involve certain resemblances and certain contrasts. As to resemblances, in each case the established stream occupies a channel at the bottom of its valley, and the banks of the channel

Fig. 14.—*Diagram of a large eroding glacier in the valleys of a subdued mountain.*

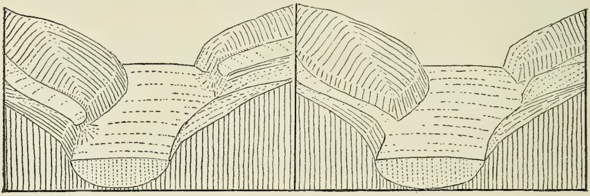


are, as a rule, steeper than the uncovered side-slopes of the valley. Assuming that the land-surface exposed to erosion is above grade, it may be believed that the early stages of a cycle of erosion would be marked by a relatively rapid incision of the (water or ice) stream-channel beneath its initial profile, accompanied by a steepening of the valley-sides above the stream-level; that inequalities in rock-resistance would for a time result in inequalities of channel and stream-slope, causing cascades or séracs; but that the inequalities of stream-slope would, after reaching maximum values, gradually be lessened, and at the same time the slope of the valley-sides above the channel-banks would be decreased by super-stream weathering. If glacial conditions continued indefinitely, an ice-stream would, like a water-stream, eventually reduce its surface-profile to an even and gentle slope: that is, the stream would become graded; and after the graded slope was reached, further deepening of the valley would be extremely slow.

In the early stages of down-cutting, a main stream of water or of ice might deepen its valley so rapidly that its surface would be below the surface of its tributaries, which would therefore fall down from their side-valleys to the main stream, as in figs. 4 and 15;

Fig. 15.—*Diagram of a young main glacial trough, with hanging lateral glaciers.*

Fig. 16.—*Diagram of a mature main glacial trough, with accordant lateral glaciers.*



but as the main stream approaches grade, it will be overtaken by its tributaries, which will then establish accordant junctions with the surface of the main stream, as in figs. 5 and 16. It is, however, of importance to note that, as Gannett pointed out ten years ago (1898), while the junctions of the stream-surfaces may thus come to be perfectly accordant, the bed of a larger, deeper main stream and the bed of a shallower tributary must always be discordant at their junction; and, if the streams were removed, this discordance would be easily seen, and the bed of the tributary would be described as hanging above the bed of the main stream. Hollows or basins in the channel-bed might be expected in both cases to result from variation in stream-velocity and in rock-resistance: the size of the basins would be roughly proportional to the size of the (water or ice) stream-channels. In the later

stages of erosion the further deepening of the water- or ice-channel is very slow; the erosive changes by the streams themselves then take place chiefly at the stream-heads, while general weathering reduces the inter-stream surfaces.

As to contrasts in the behaviour of ice-streams and of water-streams:—the ice-streams have an extremely small velocity as compared with water-streams, and this involves very different proportions between the cross-sections of the channel and the valley in the two cases. Ridges that would abundantly suffice to separate neighbouring water-streams might be overtopped by ice-streams; hence, when glaciers come to occupy a normally carved district, peculiar features may be expected to result from the overflow of ice-distributaries across low divides. The slow motion of ice-streams involves a reduction of momentum and centrifugal force to the rank of unimportant factors; and this, taken with the large size of the ice-stream, may result in the straightening of the glacial channel along a meandering valley which had been becoming more serpentine under the action of the pre-Glacial water-stream. A mature ice-stream is characteristically largest in its great upper névé-reservoirs, and becomes smaller and smaller as more and more of its volume is converted into a water-stream, which finally runs away in a small channel, of which the cross-section may not be more than 1/100,000 of that of the ice-stream at its mid-length. A mature water-stream, on the other hand, is subdivided into many minute rivulets at its source, and the trunk stream characteristically increases in volume towards its mouth. It may be pointed out in passing that the best analogy of a mountain-glacier, which ends in a warmer 'piedmont' lowland, is a mountain-stream, which ends in a drier 'piedmont' desert; but as we are here concerned chiefly with the upper part of the Snowdon glacial system, this analogy need not be pursued.

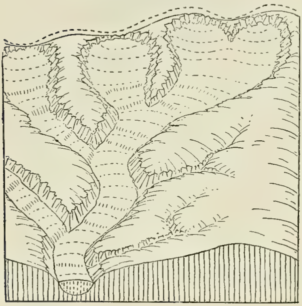
On the basis of these resemblances and contrasts, it may be inferred that when glaciers (assumed to be destructive agents) come to occupy the valleys of the pre-Glacial Snowdon district, as represented in fig. 6 (p. 307), they will proceed to scour out, enlarge and steepen the valley-heads, and gradually to convert them into névé-reservoirs or cwms, and to deepen and widen the valleys and gradually to convert them into channels suitable for the large and sluggish ice-streams. Associated with the mature enlargement of reservoirs and channels by deepening and widening, there would be a correlated sapping of the superglacial slopes, which would thereby be steepened: such steepening of valley-heads and sides would be most pronounced in the earlier stages of a glacial period, while the ice was still actively deepening its course; later, when the ice-deepening went on at a slower rate, or almost ceased, the steepened slopes would be reduced to more moderate declivity by superglacial weathering.

These systematic changes of process and of resulting form through the advance of a cycle of glacial erosion are as important in a

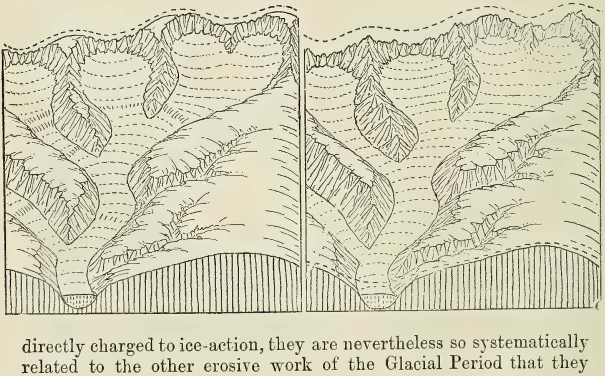
theoretical discussion as are the corresponding and more familiar changes through the advance of a cycle of normal erosion.

Under conditions such as are here outlined, let the newly established or young glacier of fig. 14 continue its work until it becomes the well-established, sub-mature glacier of fig. 17. It will then have a large névé-reservoir or cwm enclosed by cliffs, some parts of which may rise to meet the corresponding cliffs of an adjacent reservoir: there the pre-Glacial rounded spur will be converted into a sharply serrated arête; elsewhere the rounded summit-forms may resemble those of pre-Glacial time, although they will have been weathered down somewhat during the Glacial Period. Along the valley-sides which rise from the glacial stream to the ridge-lines, there will be undercut slopes which may be weathered to ragged and cliff-like walls in the resistant rocks, but may be weathered back to smooth grade in the less resistant rocks. Although the changes due to superglacial weathering, as here considered, are not to be

Fig. 17.—*Diagram of a later stage of fig. 14 (p. 313).*



Figs. 18 and 19.—*Diagrams of successively later stages of fig. 14 (p. 313).*



directly charged to ice-action, they are nevertheless so systematically related to the other erosive work of the Glacial Period that they

may be associated with, if not included under the general term, glacial erosion.

It must be understood that the work of an eroding glacier, like that of an eroding river, is accomplished gradually. In a comparatively early stage of glacial erosion the transformation of a pre-Glacial mature valley into a glacial channel will be characterized by the development of many moderate inequalities of slope, which may produce ice-rapids, as illustrated in fig. 17 (p. 316); but, with progressive advance in the cycle of glacial erosion, these inequalities will be worn down, and a smoother and smoother trough will be carved out, as illustrated in figs. 18 and 19. Duration of glaciation is therefore a very important factor in our problem. Brief glaciation would produce rough-floored troughs of a very unfinished appearance; long-lasting glaciation would produce smoothly carved troughs suggestive of well-accomplished work.

Naturally enough, results of the destructive action of the glaciers will not be fully seen until the post-Glacial milder climate is established and the glaciers have disappeared, as in fig. 21. Then the

Fig. 20.—*Diagram showing the forms revealed by the disappearance of a protective glacier.*

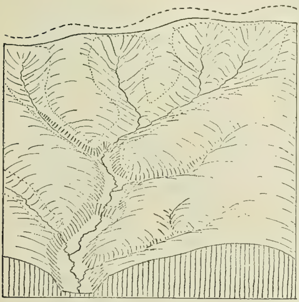
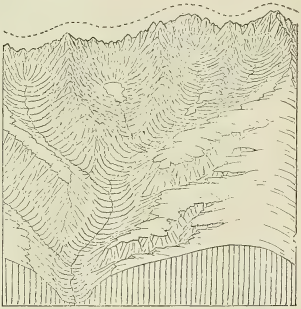


Fig. 21.—*Diagram showing the forms revealed by the disappearance of a mature eroding glacier.*



rock-cliffs of the empty névé-amphitheatres or cwms may be traced down to the well scoured cwm-floors; the empty glacial channels will be rather ragged in wall and bed where the rocks are strong, but will be well reduced to open troughs of curved cross-profile where the rocks are weaker; the empty channels will appear so large, in comparison with the streams that drain them, that they will be spoken of as 'valleys.'

XXI. Special Features of the Theory of Glacial Erosion.

As in the theory of glaciers as protective agencies, there are certain special features in the theory of glaciers as destructive agents which need special mention. One of the most significant points to consider is the varying duration of glacial action.

(*a*) If the Glacial Period were short, the ice might disappear before the cwms were enlarged enough to destroy much of the pre-Glacial mountain-form, and before the glacial channels were well excavated beneath the pre-Glacial valleys; then the sides and floors of the channels would be left ragged and uneven, as a result of the more rapid work of erosion on the weaker parts and the less rapid work on the more resistant parts; and, so long as the young glaciers were actively deepening their channels, the channel-sides would be steep and cliff-like, with a U-shaped cross-profile.

(*b*) But, if the Glacial Period were long, the channels might be worn to such a depth that further deepening would be slow; then the floor and sides would be smoothed and the channels would be widened so as to lose their U-shaped cross-profile and gain that of a round-bottom V.

(*c*) Wherever a considerable mass of weaker or more jointed rocks occurred in the graded pre-Glacial valley-floor, young ice-streams would deepen their channels more rapidly than on harder or less jointed rocks next up-stream; thus rock-steps would be produced, and once produced they would 'retreat' up-stream by the removal of rock-blocks from their face. Similarly (*d*), the channels would be eroded to a greater depth in belts of weak rocks than in belts of hard rocks next down-stream, and thus rock-basins would be formed in the channel-beds.

If (*e*) the Glacial Period were very long, some of the cwms excavated in the valley-heads might grow so large as to reduce and consume the spurs between them, and thus destroy all traces of pre-Glacial form, leaving only sharpened peaks and ridges between the cwms, as in fig. 19 (p. 316): then (*f*) the channels would be so well perfected that their sides and floors would be nearly or quite smooth, and few rock-steps would remain in their course, as in fig. 21 (p. 317).

But (*g*) rock-steps would still necessarily occur at the junction of small and large glacial channels, however long the Glacial Period endured; for it has already been shown that a discontinuity of channel-bed must persist at the junction of a small tributary with a a larger trunk stream, whether the stream be of ice or of water, however maturely the channel beds are eroded to an even slope elsewhere.

(*h*) The hanging lateral valleys would, however, not be systematically arranged in sets related to rock-steps farther up-stream in the main valley; they would be irregularly placed as to altitude, for the depth of the floor of a hanging valley below the upper limit of glaciation would ordinarily be related to the depth of the main

valley directly as the volumes of the lateral and main glaciers. Hence neighbouring lateral hanging valleys might open at different heights above the main valley-floor; and all the lateral valleys of a well-glaciated main valley should mouth or 'hang' at one height or another above the main valley-floor. (*i*) Non-hanging junctions should be expected only where two valleys occupied by glaciers of equal size come together; and here each valley might be less deep than the united valley farther down-stream. (*j*) The valley-floor rock-steps should not correspond in number, in altitude or in spacing, along neighbouring valley-systems.

(*k*) After the final disappearance of the ice from its channels, water-streams will cascade in full view on the ungraded rock-steps in the channel-beds and on the hanging valley-mouths. (*l*) The hollows of the channel-beds, occupied by lakes, will be seen to indicate only the excess of erosion in one part of the glacial channel over the erosion in the part next down-stream. (*m*) Similarly, the ledges and knobs of rock that may rise here and there in the less matured parts of the glacial channels will not be regarded as surviving elements of pre-Glacial form and hence as witnesses to the inefficiency of glacial erosion, but remnants of much larger masses not completely worn down to a smooth channel form.

One difficulty in the theory here considered is our ignorance regarding its fundamental postulate, namely, that glaciers are destructive agents. It has been already noted that glacial erosion can be observed only at the border and ends of a glacier; whatever goes on under the névé of the upper reservoir and under the heavy ice-stream in the great channel cannot be seen. It is, however, generally agreed that ordinary weathering can take little or no part in sub-glacial erosion, and that even freezing and melting, however important these changes are around the head of a névé-reservoir, may be of less efficiency in detaching rock-masses at the bottom of glaciers, because of the inferred constancy of temperature beneath the ice; but as to this, it has been suggested that changes of pressure, just sufficient to cause melting and re-freezing, might be as effective in opening joints and crevices as changes of temperature would be; and it may be added that scouring and plucking, such as are observable under glacier-sides and ends, may be still more effective under the heavy body of névé or of ice, in view of the great pressure there prevailing.

Moreover, it must be borne in mind that the rate of glacial erosion, in whatever way it may be accomplished, need not be very rapid, the only requirement in this respect being, as already noted, that it shall be significantly more rapid than normal erosion; and furthermore, in any case the cwms and valleys of glaciated mountains are the product of erosion of some kind, and in the absence of direct evidence to the contrary, it is *a priori* no more unreasonable to ascribe the erosion to large, heavy, sluggish ice-streams in association with weathering on so much of the surface as rises above

the ice, than to ascribe it to slender, light, nimble water-streams in association with weathering on so much of the surface as rises above the water. But, after all is said in favour of glacial erosion, it is still difficult to understand how cwms are excavated and enlarged under the glacier-heads, and how channels are deepened and widened under glaciers. Here we can only say, as was said on closing the consideration of the alternative theory, that if, in the face of these difficulties, the theory that glaciers are destructive should lead to consequences which are supported by facts, we should necessarily accept this theory as adequate, even though some of its processes are beyond present explanation.

XXII. A Personal Section.

Despite the efforts that I have made to present the alternative theories and their consequences impartially, it may be only too apparent that, in my own mind, the theory that glaciers are protective is essentially unsuccessful, and the theory that glaciers are destructive is, on the whole, eminently successful in leading to consequences that accord with observed facts. This opinion was not reached until after I saw in 1899 that the lateral valleys of the Alps prevailingly hang over the wide open main valleys, and that the piedmont Alpine lakes cannot be reasonably explained by the warping of normal pre-Glacial valleys. Since then, my own observations in Norway, the Tian Shan, and the Rocky Mountains have only served to confirm the opinion gained in the Alps; and at the same time similar evidence has been presented by observers from various glaciated mountains as far separated as Alaska (where Gilbert's studies are most convincing) and New Zealand (where the discussion by Andrews is no less unanswerable). But, however fully an author may be convinced of the success of one theory or another, it is always appropriate for him to revise his opinions in the presence of other theories; and that revision I have here tried to make, in view of the acceptance given to the theory of the protective action of glaciers by some geologists whose experience in the glaciated mountains of Europe is far greater than mine. In such a revision, the method here adopted seems logically correct and safer than any other as a means of solving the problem in hand, or any similar problem in which effort is made to determine the nature of invisible facts—invisible because of minuteness, or of remoteness in time or space, or of any other quality. It might, indeed, have been more satisfactory to have the consequences of the theory of the protective action of glaciers set forth by one of those who is convinced of its truth; but, as I have not been able to find from such a source a thorough attempt to carry the theory to its consequences and to confront the consequences with the facts, I have had to make that attempt in a more or less prejudiced manner myself.

Let me here emphasize a matter to which, as it would seem,

hardly sufficient weight is ordinarily allowed by field-geologists, namely, that in impartial scientific investigation, care and thoroughness are just as essential in the deduction of expectable consequences from theory and in the confrontation of the consequences of theory with the appropriate facts, as in the observation of the facts themselves in nature. Not only so: it is extremely important to deduce consequences from theories and to confront them with actual facts while one is still in the field, for otherwise the most critical and significant facts may escape detection. One sometimes finds among one's colleagues a disposition to set aside such deductions as have here been presented regarding the pre-Glacial form of Snowdon and such consequences as have here been worked out regarding the protective or the destructive action of glaciers, as too fanciful to be seriously entertained by those who are occupied in determining the actual facts of earth-structure and form. With regard to this, however, it may be fairly urged that the study of the earth to-day deals not only with observations concerning the visible facts of present structure and form, but very largely also with inferences concerning the invisible facts of past history, and that there is no safe way of determining the truth of the inferences concerning these past facts that does not involve the deduction of the expectable consequences of theory.

The standard geological literature of the day teems with inferences as well as with observations: not merely with inferences of a subordinate value, but with inferences that are of fundamental value in the science. The sedimentary origin of stratified rocks, the disturbance of slanting or curved strata, the original continuity of faulted strata, the organic origin of fossils, the lapse of unrecorded time at unconformities, the metamorphism of crystalline schists, and many other standard conclusions repeatedly met in geological essays are not facts of observation, but inferences based on facts of observation. Not only so: these and many similar inferences are not of axiomatic verity; they have had to win their way to acceptance, and however well we may be assured of them to-day, however closely their order of verity may approach that of directly observable facts, they remain nevertheless only inferences. It might be desirable to call these standardized results of geological investigation by some such name as 'facts of inference' in order to indicate their origin and to distinguish them from 'facts of observation.' But, however this may be, it is surely essential to recognize that, whatever name the 'facts of inference' may bear, they have advanced from an original stage of speculation to the assured position which they now occupy, only after submitting to the most rigorous examination by at least a generation of geologists, in the course of which the consequences of the original theoretical suggestions have been repeatedly deduced and confronted with facts of observation, while all sorts of less successful theories have been tried and found wanting.

The point to be emphasized is, therefore, that no theory or

supposition concerning the past events of the earth's history can reach general acceptance as a 'fact of inference' until the consequences that follow from it have been critically deduced so that they may be candidly confronted with the 'facts of observation': for, until this is done, no safe or impartial judgment can be reached as to the success of the supposition in representing the unobservable facts of the past.

A paragraph in Playfair's 'Illustrations' is here so pertinent that I quote it entire. After pointing out that to avoid all theoretical reasoning

'would not be caution, but timidity, and an excess of prudence fatal to all philosophical inquiry,'

this logical writer goes on to say:—

'The truth, indeed, is, that in physical inquiries, the work of theory and observation must go hand in hand, and ought to be carried on at the same time, more especially if the matter is very complicated, for there the clue of theory is necessary to direct the observer. Though a man may begin to observe without any hypothesis, he cannot continue long without seeing some general conclusion arise; and to this nascent theory it is his business to attend, because, by seeking either to verify or to disprove it, he is led to new experiments, or new observations. He is led also to the very experiments and observations that are of the greatest importance, namely to those *instantiæ crucis*, which are the *criteria* that naturally present themselves for the trial of every hypothesis. He is conducted to the places where the transitions of nature are most perceptible, and where the absence of former, or the presence of new circumstances, excludes the action of imaginary causes. By this correction of his first opinion, a new approximation is made to the truth; and by the repetition of the same process, certainty is finally obtained. Thus theory and observation mutually assist one another; and the spirit of system, against which there are so many and such just complaints, appears, nevertheless, as the animating principle of inductive investigation. The business of sound philosophy is not to extinguish this spirit, but to restrain and direct its efforts' (1802, pp. 524–25.)

XXIII. Confrontation of the Deduced Consequences of the Two Theories with the Facts of Observation in the Snowdon District.

The most strikingly abnormal forms in the Snowdon district, already briefly described, may now be reviewed in more detail under the titles of valley-heads, valley-floors, valley-sides, and hanging valleys, in order that the consequences of the two theories may be confronted by the facts of form. Choice may then be made of one theory or the other as the more reasonable, according as the consequences of one or of the other best fit the facts.

Valley-heads: cwms.—Practically all the higher valley-heads of the Snowdon district are cwms of more or less typical form, with broad floor and steep head and sides. Under the theory that glaciers are protective, we should here find forms characteristic of normal pre-Glacial erosion, except in so far as the removal of pre-Glacial waste and the slight scouring of the underlying rock may

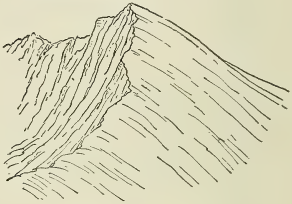
have modified them; for, in these valley-heads, the first-formed protective glaciers must have had their seats. But it is not possible to reconcile the cwms with any reasonable pre-Glacial forms. If the pre-Glacial valleys had heads as steep as the heads of the existing cwms, then the pre-Glacial valley-floors, near the valley-heads, must have been narrow; but the cwm-floors are broad. If the pre-Glacial valley-floors near their heads were as broad as the cwm-floors, then the valley-heads must have been weathered back to moderate declivity; but the head-slopes of the cwms fully deserve to be called cliffs. So far as I have read the explanations of those who accept the theory of glacial protection, there is no indication of a way of escape from this quandary; indeed, the quandary is not always recognized as such, because the theory of glacial protection has not been consciously and carefully carried out to the detailed consideration of its consequences. But there are other difficulties. Let it be accepted for the moment that the pre-Glacial valley-heads had essentially the forms of the cwms of to-day, and that when they first came to be occupied by glaciers the lower end of each glacier stood, as required by the ice protection theory, where the top of the cwm front step is now seen; then, as has already been shown, the upper margin of the protective ice-and-névé mass must have stood at the line now marked by the sudden change of slope from cwm-head cliffs to dome-like summit-slopes. As has already been pointed out, this requires a systematic relation between the height of the cwm-cliffs and the forward distance to the front rock-step. The actual location of the front rock-step in each valley-head cwm, in relation to the valley-head cliffs around Snowdon, does not appear to be such as to satisfy this requirement. If any of one of the four great cwms that head in against the summit of Snowdon were filled up to the cliff-top with ice and névé, the resulting glacier would, as well as I can estimate it, extend distinctly beyond the rock-step at the cwm front.

Another point:—Some of the sharp ridges or cribs between the Snowdon cwms are strongly serrated; they are typical Alpine arêtes in everything but altitude. Part of such a ridge is shown in fig. 22 (p. 324), a sketch of part of the spur (Crib Goch) that runs eastwards from the northern part of the Snowdon mass. Another ridge, fig. 23, running south-eastwards from Snowdon to Lliwedd, is also sharp and somewhat serrate, but more unsymmetrical, as is often the case in glaciated mountains: the sunny slope being less steep than the shady slope. Some part of the form of such serrated ridges is due to post-Glacial weathering: the rest must, under the ice-protection theory, be referred to pre-Glacial weathering, for, in the absence of any sudden change of slope in the face of the cwm-head cliffs, we are constrained (as has already been shown) to suppose that the first glaciers which occupied the cwms filled them at least as high as the present cliff-tops, and thus preserved the cliffs essentially unchanged. But to suppose that the pre-Glacial spurs of Snowdon were so narrow, sharp, and steep-sided as the present cribs, is to

contradict all experience. Subdued monadnocks of normal erosion, even when their valleys are deepened by revived streams, do not show sharp ridges; and to suppose that sharp and narrow ridges could persist when the valley-floors had gained as great a breadth as that of the Snowdon cwms is altogether unwarrantable. If, however, instead of supposing that these serrated spurs have

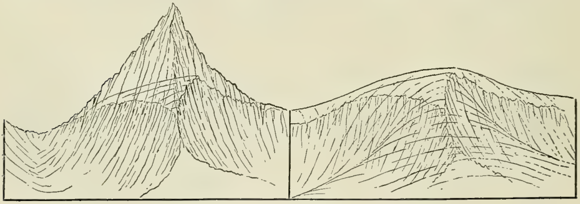
Fig. 22.—*Sketch of Crib Goch, looking north-eastwards from Snowdon summit.*

Fig. 23.—*Sketch of Lliwedd, looking south-eastwards from Snowdon summit.*



preserved their pre-Glacial form by burial, it is supposed that they rose above the névé in the adjoining cwms, then all sharpness of form ought to have been lost in the long epochs required for the deepening and widening of the lower valleys, below the rock-steps at the cwm fronts. Surely the explanation of the valley-head cwms and the sharp dividing cribs by the theory of protective glaciers is attended with difficulty.

Figs. 24 and 25.—*Diagrams illustrating the origin of the summit of Snowdon, on the theory of protective and of eroding glaciers.*



The summit of Snowdon receives very unlike explanations by the rival theories. If glaciers are protective, pre-Glacial Snowdon must have been a sharp and high peak, which may be roughly reconstructed by continuing the present cwm-walls upward till they meet, as in fig. 24. Glaciers then headed up against the walls to the height of the present wall-tops and preserved them while the

surmounting part of the peak was worn down by superglacial weathering to the blunted form of to-day, as indicated beneath the peak. On the other hand, if glaciers are destructive, pre-Glacial Snowdon must have been a large dome, which may be roughly reconstructed by extending the arch of the present rounded top over the undercut cwms, leaving normal valley-heads along the cwm-axes, as in fig. 25. Glaciers then excavated their great reservoirs in the valley-heads and sapped the surmounting slopes, leaving only a remnant of the original dome-like form. The first of these suppositions does not seem to be so consistent as the second with the pre-Glacial history of the region, or with so much of the pre-Glacial form of the Welsh mountains as has been preserved, except for normal weathering during the Glacial Period.

The cwms in the neighbouring mountain do not afford relief for the difficulty that is found with the cwms around Snowdon. Cwm Du, for example, a very sharply limited cwm in the northern slope of the dome-like mass of Mynydd Mawr, roughly drawn in fig. 3 (p. 296), is distinctly unlike the normal valley-heads of the sub-mature Cévennes or of the late mature mountains of North Carolina. The cwm-cliffs are too steep to be referred to the Tertiary cycle of erosion, which lasted so long that all cliffs must have been destroyed when uplift introduced the post-Tertiary cycle; and the revived erosion of the post-Tertiary cycle cannot be held responsible for the cliffs of the cwm, for revived erosion in non-glaciated monadnocks does not produce such features. Indeed, Cwm Du can be regarded as the result of pre-Glacial erosion only if pre-Glacial erosion is regarded as an irresponsible and arbitrary process, capable of producing, in mountains that were afterwards to be glaciated, curious forms, the like of which is not to be found in non-glaciated mountains. It is interesting to note, in passing, that a pillow-like mass of drift seems to lap on the border of Cwm Du from the west; and, as this drift-mass seems to be continuous with the sheet of drift that envelops the neighbouring Moel Trefan, I have taken it to be the work of the great northern ice-sheet, and not of the local glacier. A small moraine within the cwm may be referred to a late stage of the local glacier.

Under the theory that glaciers are destructive agents, the valley-head cwms of the Snowdon district are regarded as normal pre-Glacial valley-heads that have been significantly enlarged and deepened by glacial erosion, with pronounced steepening of the side and head walls, partly by direct glacial action, partly by superglacial weathering. So much of the dome-like mountain as is still seen above or alongside of the cwms is regarded as preserving in a general way the quality of subdued form that the mountain possessed in pre-Glacial time, but as having been lowered by an unknown amount by general weathering during Glacial time. The difficulty, in this view of the case, is that no one yet knows just how glaciers can erode retrogressively, so as to enlarge as well as to deepen their névé-reservoirs. It is supposed that they scour and

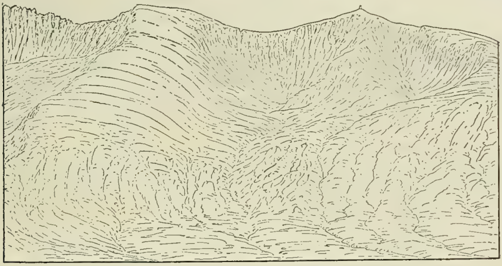
pluck the rock-wall and bed, and it is believed that freezing and thawing aid in prying off large blocks in the bergschrund around the névé-head, as far down as weather-changes can penetrate. But, as the examination of what is now going on under the ice of glacier-filled cwms is limited to the moderate depth to which hardy observers can descend in the marginal crevasses, the actual behaviour of the ice in the enlargement of a cwm is not yet well-determined by direct observation. Hence such support as is gained for the supposition that glacier-heads can erode retrogressively while they grind down their beds, must come for the present chiefly from the degree of success with which the assumption of glacial erosion can explain the whole series of abnormal forms in glaciated mountains.

If we now, for a moment, provisionally accept the idea that cwms are the work of glaciers, there remains an interesting enquiry to make regarding the particular pre-Glacial forms that favoured the first accumulation of snow as the embryo of the glacier that was to be developed later. The suggestion may be made that, when all the cwms of such a region as North Wales, for example, are studied out and catalogued as to altitude and dimensions, it may be possible to find on the lower outskirts of the higher and more heavily glaciated district, some small incipient cwms, in which the pre-Glacial form is little changed because the ice-action there was short-lived and weak. By careful classification it may be possible to arrange all the cwms in a series, from these slightly developed forms to the maturely excavated cwms of Snowdon itself. Passing then from North Wales to a more severely glaciated region, such as the Sierra Nevada of California, or Norway, cwms in a still later stage of development than those of Snowdon may be found. When this has been done, it will probably be possible to determine the kind of pre-Glacial valley-heads that favoured the formation of a local glacier and the excavation of a cwm; at the same time, it will be possible to frame a systematic method of describing cwms in terms of their stage of development, as well as in terms of their size; and thus a decided advance will be made in the study of this class of land forms. Still more: as experience broadens, it will probably become possible to classify cwms not only in terms of their own development, but also in terms of the stage of pre-Glacial development of the mountains and valleys in which the cwms have been excavated; and, when this is accomplished, we shall have an approach to a really philosophical method of treating these curious forms.

As a small contribution to this enquiry, mention may be made, first of a faintly developed cwm on the south-western face of Mynydd Mawr; it is merely a slight recession of the mountain-base and a moderate increase in the steepness of its side slope, without the development of distinct head-cliffs. Later in the series is the well-developed Cwm Du, on the northern face of the same mountain; here the cwm-floor is well scoured out, and the cliffs at the head and

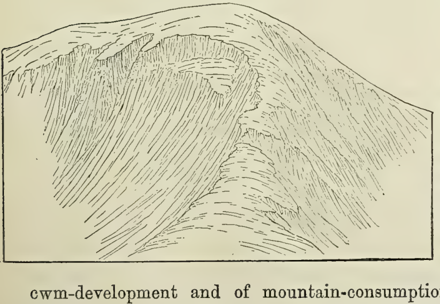
sides are strongly marked, in contrast with the gracefully rounded form of the mountain as a whole. But the cwm is of so moderate a size that the great mass of the mountain still remains above and alongside of it. Now looking southwards across Nantlle Valley to the ridge on its southern side, we find several cwms, one of which is shown in fig. 26 (below). This one is separated from another (Cwm

Fig. 26.—*Sketch of a cwm on the south side of Nantlle Valley, looking southwards. (The beacon is on Mynydd Tal-y-Mignedd.)*



Dwyfawr) on the farther (south) side of the mountain by a narrow, grass-covered ridge, slightly breached at one point; the ridge is sketched in fig. 27, as seen from the west. Evidently the col is just on the verge of becoming a crib or arête: here the cwms occupy a large part of the original mountain-mass. Next farther west two cwms (on the northern slope of Craig Cwm Silin, beyond the limits of the outline-map, Pl. XIV) have partly consumed the spur between them, so that they open laterally into each other. Thus various stages of cwm-development and of mountain-consumption are easily distinguished. The same is true on Snowdon, as is indicated at the opening of this article. The Ordnance Survey map (Snowdon sheet) is very expressive in showing the narrow ridges between

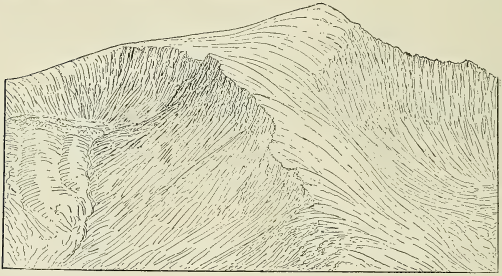
Fig. 27.—*Sketch of the head ridge of fig. 26, looking eastwards.*



the encroaching cwms, and the fractional remnants of the mountain-dome still unconsumed.

The maps of the Snowdon district indicate a greater frequency of large cwms in valley-heads which open northwards or north-eastwards than in those which open in the opposite direction. This is a feature that has been noted in various other glaciated mountains, and is evidently to be associated with the protection from sunshine that is afforded in valleys of northern aspect. It would be interesting to learn whether the cirques of mountains in the Southern Hemisphere are more commonly open to the south and south-east. A correlated feature is found in the unsymmetrical slope on the opposed sides of many ridges, as already noted: the north-eastern slope may be a precipitous cliff, while the south-western slope is of much more moderate declivity. This rule appears to hold in the south-eastern (fig. 23, p. 324) and north-western (fig. 28) spurs of

Fig. 28.—*Sketch of the north-western spur of Snowdon, looking south-eastwards from Moel y Cynghorion. Cwm Dur-arddu is on the left; Cwm Clogwyn on the right.*



Snowdon; also in the ridge (fig. 26, p. 327) between the two cwms that open into Nantlle Valley next west of Y Garn, and in various other cases. It is presumably to be explained by unlike rates of weathering on the two slopes, as has been suggested by Dr. G. K. Gilbert in his discussion of the unsymmetrical inter-cirque ridges of the Sierra Nevada (California).

The depth of glacial erosion indicated by the cwms of Snowdon and its neighbours may be roughly inferred by reconstructing the whole moel from so much of it as remains; but, besides the depth thus shown, something must be added for the loss of the moel itself by general weathering during the Glacial Period. I am unable to offer any satisfying estimate of the latter quantity. Of the former, the construction of several curves gives measurements ranging from 200 or 300 to 500, 600, or even 700 feet.

Valley-floors: lakes.—The lakes which occur abundantly about Snowdon are all of moderate or small area and depth. They are well treated in a paper by Dr. Jehu (1902), from which it appears that Llyn Llydaw, in the upper part of Cwm Dyli, where a sounding of 190 feet was made, is one of the deepest. This lake, occupying a high-standing basin in the floor of the great eastern cwm of Snowdon, has, like many of the other small lakes hereabouts, every appearance of being contained in a true rock-basin; if any drift-barrier does occur at the outlet, its depth cannot be nearly as much as 190 feet. Llyn Cwellyn is a valley-floor lake, west of Snowdon, with a depth of 122 feet. Its lower end is half a mile above a rather pronounced rock-step in the floor of its broadly rounded valley; it is against all reasonable possibility that a drift-filled gorge, 122 feet deep, should exist in this barrier down which Afon Gwyrfai cascades; hence Cwellyn also must occupy a rock-basin. The two lakes of the Gwynant Valley have the appearance of being rock-basins: they gain interest, because of association with picturesque rocky hills by which the valley-floor is interrupted; and these, I take it, are so many examples of unfinished channel-bed smoothing. Where the valley widens, east of Llyn Dinas, the hummocky form of the bed of the great glaciers that there scoured a wide channel is very pronounced and characteristic. Some of the smallest lakes in the cwm-floors are, on the other hand, pretty surely enclosed by morainic barriers, at least in good part.

At Beddgelert the valley of Afon Glaslyn is broad and flat-floored: about a mile to the south, the valley is narrowed to a rock-walled gorge, the Pass of Aberglaslyn, where the stream has a rapid fall: it would seem as if the open valley by Beddgelert were of rock-basin form, and that it may well have held a lake for a time; but the lake is now destroyed by alluvial aggradation of the basin, and by erosion of the outlet-gorge. Similar examples are well known in the Alps.

It is evident that the rock-basin lakes cannot be the result of pre-Glacial erosion, for normal erosion does not produce such rock-basins. Under the theory of ice-protection some special process must be invoked to account for the basins. Drift-barriers, frequently appealed to, are as a rule not admissible here. Warping, still often accepted as a means of accounting for the great piedmont lakes of the Alps, is not admissible there, for the reasons that Wallace clearly set forth some years ago. As to a recent warping of the Snowdon district, it would be difficult to prove or disprove. If it occurred, it might well account for various rock-basins, but it ought to have other recognizable consequences also: for example, a warping that would produce Llydaw or Cwellyn ought to deform, or crush, or rend some of the neighbouring ridges; but no signs of such disturbance are noted in relation to the rock-basins.

Under the theory of ice-erosion, rock-basin lakes are not to be regarded, as they too often have been, as marking the full measure of erosion, but as indicating simply the excess of ice-erosion in the

basin as compared with the erosion farther down the valley. It has been urged that, given a basin in the path of a glacier, the retardation of the bottom part of the ice in the depression, and the faster motion of the ice over the outlet would result in the obliteration of the basin; and, if no other factors entered into the problem, this conclusion might well be accepted. But other factors do enter, especially in the way of variations of rock-resistance and of ice-pressure and velocity; hence it is perfectly reasonable to believe that, if an eroding glacier found no basins in the pre-Glacial valley of which it took possession, it would tend to produce basins wherever the rocks were more easily excavated, or wherever the ice-motion was accelerated. Naturally, a balance would in time be struck between the forces of excavation of the basin and erosion of the outlet; and then erosion would proceed at essentially the same rate in the basin and at the basin-outlet. But no one knows what measure of inequality the bed of a glacial channel may have when such a balance is reached. Longitudinal profiles drawn on a true scale are instructive in this connexion; they usually show a much less inequality of valley- (ice-channel) floor where lakes occur than is indicated in freehand profiles of the same district. This is particularly true in a district where the lakes are so small as in North Wales. Indeed, if glaciers did any erosive work in North Wales, the lake-basins are so small a part of it that they need hardly be considered in the present discussion. Even if the valley-floors had not been here and there deepened in excess so as to hold lakes, there would still be an abundance of abnormal forms in the Snowdon district, more indicative of strong glacial erosion than are the lake-basins.

Valley-floors: rock-steps.—Abrupt rock-steps extending all across the broad floors of wide opened valleys are common in the Snowdon district. They would be well illustrated by true-scale profiles through Snowdon summit; but the construction of such profiles is not easy, because the Ordnance Survey map has a contour-interval of 250 feet at altitudes over 1000 feet. One profile might pass from the eastern to the western cwm; the other from the north-western to the southern cwm. The eastern profile in Cwm Dyli would show three strong steps; and a fourth might be counted if the series began with a small uppermost cwm, not shown on the 1-inch Ordnance Survey map. Lakes (Glaslyn and Llydaw) occupy rock-basins between the upper steps, and these once supplied a dashing torrent on the lower step; but most of the water is now taken down in large pipes to an electric power-station, the electric current being carried thence by many wires to the slate-quarries at Ffestiniog, Llanberis, and Nantlle. The north-western (Cwm Dur-arddu) and the western (Cwm Clogwyn) profiles would each include two well-defined steps; but the steps do not agree with each other in altitude or in height, and they necessarily disagree with the three steps in the eastern profile. The southern

profile (Cwm Llan) would have but one step; and this one is of exceptional form, being cut back by a rather wide notch, a feature that does not appear in the other steps. A profile might be added through the north-eastern cwm (Glas); this would, I believe, show two steps, but the wide-spaced, high-level contours of the 1-inch Ordnance map do not enable one to draw the profile satisfactorily. Some of the steps in the profiles occur at the junction of smaller with larger valleys: such are the second steps in the north-western and western cwm-valleys, and the fourth step in the eastern cwm-valley. The valley of Afon Gwarfai has two steps of 100 or 150 feet, above and below Llyn Cwellyn. A third step or slope seems to occur several miles farther north-west, beyond a stretch of broad and flat floor (Bettws Garmon); and this, I venture to suggest, is due to the confluence of the local Welsh glacier with the great ice-sheet from the north.

No consistent explanation of the steps can be found under the theory of ice-protection, for they do not stand in the particular relation to one another, nor in the proper position with respect to the cwm-head cliffs, that is demanded by that theory. But, apart from their disagreement in number and height, another difficulty has already been mentioned in the explanation of rock-steps by ice-protection: namely, that the normal erosion of a broadly open, flat-floored valley below a rock-step—such a valley, for example, as the Upper Gwynant Valley below the steep 700-foot step from Cwm Dyli—must have required a long period of time; and yet during all this period, the end of the protecting glacier must have been nicely held at the top of the step. If it advanced forward for a part of the period, then the excavation of the part of the valley thus ice-covered would have been delayed, and the step would have been of uneven slope; if the glacier-end retreated for a part of the period, then its water-stream would have cut a large notch in the face of the step; and such notches are characteristically wanting—the notch in the rock-step at the lower end of Cwm Llan being the only one of the kind among ten others in the immediate neighbourhood of Snowdon. Even if a glacier should hold its end nicely at the top of a step, it is not to be understood why the stream which issues from the glacier did not trench itself in the face of the step, during the long period in which the same stream deepened the unprotected valley below the step, and during the much longer interval required for the widening of the lower valley by the slower process of lateral erosion, after its deepening was practically completed down to grade. I believe that each one of these difficulties is fatal to the ice-protection theory. It may be added that the prevailing absence of deep gorges in the face of rock-steps is a strong reason for ascribing very little glacial erosion to subglacial streams; for precisely at these points of rapid descent in the glacial bed, where subglacial streams ought to be working most effectively, there is practically no sign that they worked at all. The trifling depth of the channel in which most of the streams run down the face of the

rock-steps is most significant; one would have thought that post-Glacial time alone might have sufficed for a deeper entrenchment than usually occurs. The waste-heaps of the Glanrafon slate-quarries east of Llyn Cwellyn, in the face of the second rock-step outside of the western (Clogwyn) cwm of Snowdon, would about fill the little gorge that the stream (Afon Treweunydd) has cut in its cascading course down the face of the step. Indeed, the enormous waste-heaps by the quarries of Llanberis, Ffestiniog, and Nantlle would, I fancy, without counting the great amount of good slate that has been marketed, about equal the volume of rock eroded from all the post-Glacial stream-gorges in the Snowdon district.

Under the theory of ice-erosion, rock-steps in the valley-floors are necessarily expectable features in a glaciated district where the glaciation did not last long enough to allow the perfect reduction of the ice-channels to a maturely even grade. It is not necessary to make special suppositions regarding long halts of the glacier-ends at particular places. It stands to reason that, when a normally eroded pre-Glacial valley comes to be occupied by an eroding glacier, the work of valley-deepening cannot be accomplished evenly or all at once. The work demands time; and, during its advance, it is most reasonable that the deepening should be faster in some parts than in others. It is a matter of course that channel-floor hollows and channel-floor steps should be produced along the course of the glacier, if it be regarded as a destructive agent. It is equally expectable that, if time allowed, the steps developed in the more youthful stages of glacial erosion should be worn away in the more mature stages; and hence that glaciated valleys (glacial channels) should, like cwms (glacial reservoirs), be described in terms of the stage of advance reached in the long process of modifying a normal pre-Glacial valley into a young, mature, or old glacial channel. It is evident enough that the stage of maturity was not fully reached in the Snowdon district. The valleys—or glacial channels, as we should call them in the present consideration—are, however, more nearly mature in their lower courses than in their upper courses, and this is a not unnatural arrangement.

It is difficult to determine whether rock-steps in valley- (channel) floors are in any definite way related to differences of rock-structure. So far as the geological maps go, no constant relation of steps to structure can be found in the Snowdon district. In some cases a rock-step lies close to a boundary-line between two formations; in other cases a step occurs within the area of a single formation: in some instances the step-face is parallel to the strike of the formation; in others it is oblique or transverse. Even where the step lies near the boundary between two formations, it does not clearly appear that the upper level is of more resistant, and the lower level of less resistant, rock; for when the two formations concerned are followed up to a ridge-crest, the height of the ridge shows no marked change at the boundary between the two. In this connexion, however, two points should be borne in mind. First, that all the

formations of the Snowdon district are relatively resistant, as has already been stated. Second, that in many non-glaciated districts of massive rocks, young water-streams may show numerous little falls between short, roughly-graded reaches; and that in such cases one may fairly assume that the streams have discovered differences of resistance which the eye and the hammer cannot detect. No one makes a mystery of the work of young cascading water-streams because such differences of resistance are not apparent; and similarly in the case of young glaciers, it is the most natural thing in the world that, if they erode at all, they should discover differences in the resistance of the bed-rocks, which may not be immediately apparent to us. The differences may be due to greater or less resistance to crushing or scouring, to greater or less frequency of jointing; to the attitude in which planes of bedding, schistosity and jointing stand in relation to the ice-motion. Moreover, it must be borne in mind that, in the work of a glacier as in that of a stream, the element of time enters largely. Abundant opportunity is afforded to the eroding agent for the discovery of every element of weakness possessed by the underlying rocks. In view of all this, the surprising thing would be to find an immaturely glaciated district in which no rock-steps broke the slope of the valley-floors. But, as in the case of cwms, just how the ice works to produce rock-steps is not yet made clear. It appears reasonable to me to accept the possibility of plucking as an important part of the process; but for the present no full explanation of it can be given.

A modification of the theory of ice-erosion ascribes a large part of the erosion of trough-like glaciated valleys to the action of subglacial streams. I propose to consider this theory in detail elsewhere, and take occasion here only to point out that it is difficult to believe that an agency, which did not cut down the rock-steps in the valley-floors and at the mouths of the lateral hanging valleys, could greatly deepen the valleys themselves.

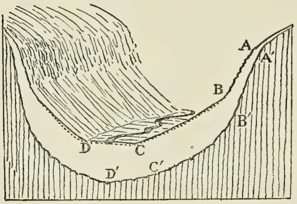
Valley-sides.—Many of the valleys in the Snowdon district have, when considered in cross-section, what is commonly called a U-shaped cross profile; but the term U-shape generally overdoes the matter, for the valley-sides are not vertical. Catenary seems a better term with which to describe the cross-profile of the glaciated valleys in the Snowdon district; but it is not intended thereby to imply that the cross-profiles have exactly a catenary curve. When considered longitudinally, the valleys around Snowdon are frequently rather even-sided or trough-like for significant distances, without advancing spurs or receding embayments; but sometimes the valley-sides are of a peculiarly uneven, ragged, craggy form, pleasingly picturesque to the eye, yet perplexingly difficult to describe in words; they are occasionally steep and rugged. These several forms will be considered in succession.

The smooth-sided trough of catenary cross-profile is well shown in the Gwynant Valley, on either side of Llyn Gwynant and farther

up stream; and again in the valley of Afon Gwyrfai on each side of Llyn Cwellyn. In both these localities little streams from short valleys in the uplands rush down the even valley-side slopes with a very slight entrenchment; yet they are already actively at work in the establishment of a better relation with the main stream.

Under the theory of ice-protection, the smooth troughs are the work of normal erosion during a part of the Glacial Period when the ends of the local glaciers stood at the top of the next up-stream rock-step; but it may be asserted with much confidence that the trough-like valleys around Snowdon could not possibly have been produced under such conditions. A trough-valley with a catenary cross-profile may doubtless be sometimes produced by normal erosion in non-glaciated regions, provided appropriate structures compel the form; but, in the Snowdon district, trough-valleys occur in various stratified and massive structures of various attitudes, which are not adapted to their production by normal erosion. The usual features of a normal, nearly mature valley in which the side-walls still retain steep or cliffed upper slopes (AB, fig. 29) are the thin sheet of retreating talus (BC) beneath the cliff, and the shallow alluvium of the flood-plain (CD) beneath the talus. A glaciated trough-valley, in which little post-Glacial waste has gathered, may have steep upper slopes (A′B′) below which some growing talus (B′C′) may already have accumulated; but this may not suffice completely to conceal the curving rock-slope (C′D′) which reaches to the stream. The flood-plain element is here not essential, although often in process of formation by post-Glacial aggradation.

Fig. 29.—*Cross-profiles of a normal mature valley and of a glaciated valley.*



Furthermore, if the trough-valleys of the Snowdon district had been widened by normal erosion, the side-streams would have eroded side-valleys of much greater depth than the trifling little 5- or 50-foot gulleys of to-day, and thus the trough-like continuity of the valley-sides would have been interrupted.

Under the theory of ice-erosion, a trough-like channel is a natural expectation; for the heavy and sluggish ice-stream would tend to deepen and reshape any other kind of channel until its cross-profile assumed a catenary curve. When thus maturely reshaped, the channel—which we call a 'valley' to-day, in the absence of the glacier that once occupied it—would have rather smooth sides, because the ice would have trimmed away all salients and spurs; and because the presence of the ice would have

prevented the formation of side-gulleys and ravines by cascading streams. It is only since the ice has melted away that the cascading streams have been at work, and in this post-Glacial epoch there seems not to have been time for the accomplishment of much ravining, even though the streams are rapid and vigorous torrents.

It is interesting to quote in this connexion a phrase of Mr. Whymper's, in his 'Scrambles amongst the Alps':—

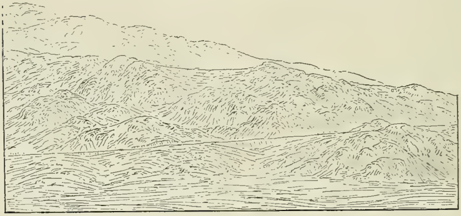
'Given eternity, glaciers might even grind out valleys of a peculiar kind. Such valleys would bear remarkably little resemblance to the valleys of the Alps. They might be interesting, but they would be miserably unpicturesque' (2nd ed. 1871, p. 331).

This probably means that the valleys ground out in an eternity of time by large glaciers would be smooth-sided troughs, 'miserably unpicturesque' because of the simplicity and uniformity of their sides. The idea is a good one, and ought to have been followed up. The Norwegian fiords are, as I understand them, valleys (that is, channels or troughs) of the peculiar kind that long-lasting glaciers might grind out: they have little of the graceful variety of form that is produced by normal erosion, yet they fail of having been so perfectly smoothed as to have become 'miserably unpicturesque'; and in size alone they are magnificently imposing. So in most glaciated valleys, it would seem that glacial action did not continue long enough to produce ideally smooth sides or smooth floors; yet the parts of the Welsh valleys instanced above really do present just such trough-like forms as would appear to be appropriate to maturely eroded glacial channels. The best example of this kind that I have seen is by Llyn Cwellyn, where the northern side especially is smoothed in a great concave slope, practically uncut by ravines, although several streams run down it. It is by no means miserably unpicturesque, but charmingly graceful, and full of significant meaning. In the other fine example, the Gwynant Valley on either side of the lake of the same name, the view south-westwards into this trough-valley from the pass at its head is certainly as charming a sight as one may wish to see; and the graceful concave slope of the valley-sides, which are singularly free from entrenchment by side-ravines, is not its least pleasing element. I do not believe that it is possible to explain either the concave curve or the absence of ravines, if these valleys are taken to be the work of normal erosion. But, if the valleys are regarded as the work of glacial erosion, which deepened and widened pre-Glacial valleys, their form is perfectly expectable; glaciers would naturally wear out just such channels if they had time enough. Probably the troughs were better finished by Llyn Gwynant and Llyn Cwellyn than elsewhere, because the rocks there were more yielding.

Ragged or craggy slopes are seen at many points; for example, on the southern sides of the broad masses (Yr Aran and Craig Wen) into which the southern spur of Snowdon expands near Beddgelert; and in the eastern side of the upper (south-eastern) end

of Gwarfai Valley, fig. 30 (see also fig. 7, p. 308), where the narrow-gauge railway picks its way among the crags. Such crags on the channel (valley)-sides correspond to the hummocks on the slope of the widened glacial channel east of Llyn Dinas. They are strangely unlike the simple slopes of normally subdued mountains; they must impress one who, having gained his general impressions in a non-glaciated district, sees them for the first time, as in some way 'out of order'; for they do not appear to have been formed by the down-hill streaming of water and the down-hill creeping of

Fig. 30.—*Sketch of crags near the head of Afon Gwarfai Valley, looking eastwards.*



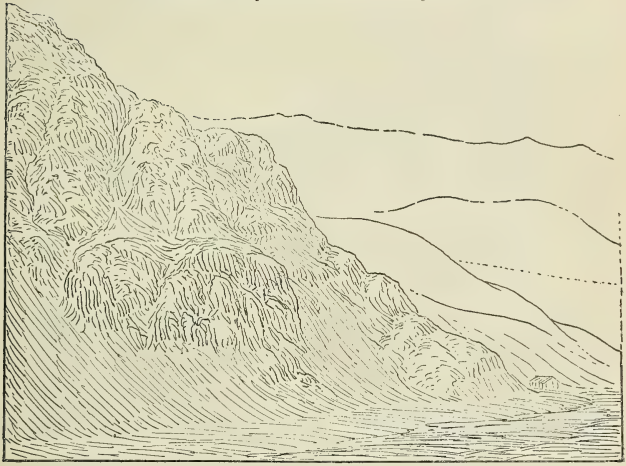
waste. It is, however, quite possible that the rocks of normally subdued mountain-masses may be so unequally penetrated by weathering and decay, that a moderate amount of glacial scouring would suffice to transform their sweeping slopes into the disorderly craggy forms of glaciated mountains; and perhaps such an amount of erosion is not beyond the allowance of destructive work attributed to ice by those who regard glaciers, on the whole, as protective agents. Hence these features, whether on the floor or on the sides of glacial channels, are not of critical value in making choice between the alternative theories.

Several examples of valley-side cliffs may be instanced. One occurs near the head of Gwynant Valley, just under the south side of Cwm Dyli, fig. 31 (p. 337). A remarkably fine cliff occurs on the east side of the dome-like Moel y Cynghorion [so named on the Ffestiniog (N.E.) quarter of Sheet LXXV of the Geological Survey map, but without a name on the 1-inch Ordnance Survey Snowdon sheet, 3rd ed.; its southern slope is shown in the left part of fig. 7, p. 308]. Still other cliffs occur on the north-east and south sides of Mynydd Mawr; the first of these is roughly shown in fig. 3 (to left of centre); the second, known as the Craig y Bere, is sketched in fig. 32 (p. 338). Under the theory of ice-protection, all these cliffs must be referred to the work of normal erosion while the ice stood at the next up-stream rock-step; but it is unreasonable to think that cliffs of this kind could be so produced, for there is no sufficient peculiarity of structure to cause them. The first example mentioned above occurs in a mass of volcanic ash, which is reduced to

a graded slope a little farther down the valley. The second occurs in a body of uniform slates, which are elsewhere, except in cwm-heads, reduced to graded slopes. The two cliffs of Mynydd Mawr might, at first sight, be referred to the action of normal erosion on a body of 'intrusive hornblende-porphyry,' which constitutes a large part of the mountain-mass; but a closer examination must lead to a different conclusion. The cliffs do not, according to the geological map, follow the border of the porphyry and overlook the neighbouring slates, as would be the case if the resistant porphyry and the weaker slates had been acted on by normal erosion; hence these cliffs, like the others, are suggestive of some abnormal process.

Under the theory of ice-protection, no adequate explanation for

Fig. 31.—*Sketch of ragged cliffs under Cwm Dyli, looking northwards from near Lake Gwynant.*

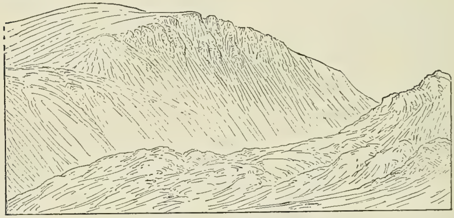


cliffs such as these has been given. Under the theory of ice-erosion, they may be accounted for in two ways, according to their position. The rugged cliffs beneath Cwm Dyli and on the north-east side of Mynydd Mawr rise directly from their valley-floors, and represent channel and valley-sides in an unfinished stage; longer duration of ice-action would have made them smoother. The first of these two examples, sketched in fig. 31 (above), is at a sharp turn in the path of the Cwm Dyli glacier, and is not high enough to have reached up to the ice-surface. Here glacial rasping would have had to do much more work than has been done, before an easy turn could have been made; the cliff has a steep and ragged rock-face, because

it was suffering an active attack by the ice. The second example occurs where a porphyry-spur of Mynydd Mawr has been truncated from its former projection into the valley of Afon Gwarfai: its form is bold and rugged, to a degree that is altogether inappropriate to the work of normal erosion on the side of an open-floored valley, a third of a mile wide; the widening of such a valley by normal erosion proceeds gently, but these cliffs have been shaped by some severe agency. The lower part of the cliffs is simply the unfinished or immature side of an overdeepened glacial channel; immature because the rock there is more resistant than the slates next up-stream by Llyn Cwellyn, where the channel is beautifully smooth and mature, as already noted. The higher part of these cliffs rose above ice-level and is due to sapping of the lower part by the ice.

The cliffs on the south side of Mynydd Mawr (fig. 32) and on the

Fig. 32.—*Sketch of the Craig y Bere, on the south side of Mynydd Mawr, looking north-eastwards from a cwm south of Nantlle Valley.*



east side of Moel y Cynghorion stand high above the valley-floors, to which the descent is made by long talus-clad slopes: hence their upper parts were probably for much of the Glacial Period exposed to superglacial weathering, rather than to direct glacial erosion. But they are situated where strong glacial erosion of the lower slopes is expectable: in the first example, because of glacial overflow into Nantlle Valley, as will be explained below; in the second example, because of a sharp northward turn of the glacier from Cwm Dur-arddu. The upper parts of these cliffs may therefore be ascribed to the sapping of the slopes below them by glacial erosion, and not to direct ice-action. Similar but smaller sapped cliffs occur on the north side of Y Garn, facing those on the south side of Mynydd Mawr.

A paragraph may be given to the great cliffs which rise on each side of the deep Llanberis 'pass' or valley, next north of Snowdon. Under the theory of protective glaciers, Llanberis Valley must be regarded as of pre-Glacial origin, deepened as a result of the successive uplifts of the district which gave rise to the steps in the neighbouring valleys. But as thus explained, it is not

reasonable that the ice from Cwm Glas, high up on the south side of the valley, should not have descended into it, and have given rise to rock-steps at successive positions of the glacier-end, comparable with those of neighbouring valleys. Until this difficulty is cleared away, the Llanberis Valley must be regarded as beyond explanation by the theory of ice-protection. Under the theory of ice-erosion, that valley is an example of energetic work of ice-channel deepening, carried forward to a fair degree of maturity in its down-stream part, but still young and ragged near its head. To as great a height as the valley was filled with ice, the cliffs are due to glacial scour; at greater heights, the cliffs appear to result from weathering and sapping. There is reason to think that the col at the head of this valley in pre-Glacial time was farther west and decidedly higher than the present col; and that we have here a case of strong erosion by an ice-stream that overran a divide: of which, more below.

Hanging lateral valleys.—The valley-systems in the immediate neighbourhood of Snowdon are hardly large enough to exhibit hanging lateral valleys in their perfection; but several good examples are seen of short cwm-like lateral valleys, distinctly hanging over their wide-open main valley-floors. It is singular that more was not made of these very curious features in the descriptions of Wales years ago; but the hanging cwms and valleys around Snowdon do not seem often to have called for special remark as distinctly abnormal features. This can hardly be interpreted otherwise, than as meaning that no sufficient scheme of normal land-sculpture was in the mind of the earlier students of this district.

The short hanging valleys on the south side of Nantlle Valley will be first mentioned. Account of the fine cwms at their heads has already been given. Not less striking is the steep main-valley side, down which the cwm-torrents cascade 300 or 400 feet, with only a small beginning of entrenchment, as in fig. 26 (p. 325). One (or two) similar but less conspicuous hanging valleys occur on the north side of Nantlle Valley. The trough-like evenness of the main valley-sides, which truncate spurs and hanging valleys indifferently, is also a striking and significant feature.

The valley of Afon Gwarfai is joined near its head by the valley of the western cwm of Snowdon, with a pronounced break of 500 feet between the two, roughly shown in fig. 7 (p. 308). An exceptional feature is here to be noted: the cwm-valley would to all appearance be the source of the chief glacier for the valley of Afon Gwarfai; hence the path of this glacier ought to be the main glacial channel, and over this channel all the branch valleys should stand at discordant levels. The reverse is true; for the broad-floored path of the western cwm-glacier stands high above the valley-floor of the upper part of Afon Gwarfai. I have interpreted this as meaning that the upper Gwarfai Valley received much ice from across the flat pass that separates it from the Afon Colwyn

Valley. The valley of Afon Gwarfai receives other cascading streams from two short hanging cwm-valleys on the south-west, roughly shown in fig. 3 (p. 296); one is alongside of Llyn Cwellyn, and the other is a mile farther down stream. Both of these are fine examples: the second is the sharply defined Cwm Du in the north side of Mynydd Mawr, already described.

The Gwynant Valley has a number of small torrents on its sides, cascading from small hanging valleys on the higher slopes; one of the best of these is on the north-west side of the valley, about a mile and a half above Beddgelert, and another enters the southern end of Llyn Dinas from the south. The exceptional recession of the hanging valley which enters the Gwynant Valley from the southern cwm of Snowdon has already been mentioned.

The north-western cwm-valley of Snowdon hangs 200 or 300 feet over the Llanberis Valley; the fine waterfall that is here cutting a ravine in the lip of the hanging-valley mouth is a picturesque feature in the ascent of Snowdon by the rack-railway, just after leaving the town of Llanberis. Several small high-level hanging valleys supply cascading streams on the north-east side of the Llanberis Valley.

It is difficult to imagine how these strikingly abnormal features can be accounted for under the theory of glacial protection. In every case, the main valley is not a narrow, vertical-sided chasm, over which a hanging lateral valley is a normal feature, but a wide open thoroughfare, with respect to which a hanging lateral valley is absolutely abnormal. To suppose that the glaciers of the hanging valleys held their ends in fixed positions during all the time required for the deepening and widening of the main valleys is unwarranted by anything that is known of existing glaciers. To suppose that, if the glaciers really did hold their ends in fixed positions so long, they could have selected stopping-places so significantly related to irrelevant features—the main valleys to which the hanging valleys are tributary—is unreasonable, to say the least. To explain these hanging lateral valleys by any processes of normal erosion, aided by tilting, uplifts or anything else, but independent of ice-protection or of ice-erosion, would require the abandonment of the well-grounded principles of valley-development as determined in non-glaciated regions. On the other hand, the explanation of the hanging lateral valleys under the theory of ice-erosion requires no special or peculiar suppositions. The explanation is a corollary of the proposition that glaciers erode their beds. It necessarily follows, either from the more rapid channel-deepening by a main glacier than by a side-glacier in the early stage of a cycle of glacial erosion; or from the inability of a smaller side-glacier (or a side water-stream) to erode as deep a channel as that of the larger main glacier, however long the glacial cycle continues.

The depth of glacial erosion in a main valley is roughly indicated by the discordant altitude of the hanging lateral valleys, as well as

by the height of the main valley-floor steps; but in both cases allowance must be made for the glacial erosion of the lateral valleys, or of the bench at the top of the rock-steps. As well as I can estimate it on this basis, the total deepening of the main valleys by glacial erosion in the Snowdon district may be from 200 to 400 feet, and in some cases 500 or 600 feet. It is important to note that, with the downward erosion, a much greater lateral erosion must be associated: this may easily amount to 1000 or 1500 feet, both right and left, in some of the larger valleys where the downward erosion measures 300 or 400 feet. These estimates for downward erosion correspond roughly with those obtained from the cwms. In both cwms and valleys glacial erosion has therefore been of importance in shaping the present landscape.

Glacial overflows.—A striking case of glacial overflow occurs at the head of Nantlle Valley. The growing ice-streams from the Snowdon centre must have filled the valley of Afon Gwarfai (with outlet to the north-west) and Afon Colwyn (with outlet to the south), and have become confluent across the divide between these valleys; then the ice must have overtopped the somewhat higher divide at the head of Nantlle Valley, of which the outlet is to the west. From this divide a fairly considerable ice-stream, overflowing westwards, must have been joined by several small glaciers, and must have had a comparatively rapid slope to the sea. It would be reasonable, even under the theory of ice-protection, to expect some moderate amount of erosion as a result of the intensified action that should follow from the accelerated motion of a glacier overflowing a pass into a valley-head: under the theory of ice-erosion, such points of overflow are naturally enough the very places where strong erosion would be expected. Further, the more a pass is worn down, the more ice will flow through it; and the more ice flows through the pass, the deeper will it be worn down: at the same time, the col will be shifted towards the higher valley. Changes of this kind are clearly indicated at the steep head of Nantlle Valley. Great cliffs rise on the north to Mynydd Mawr, and somewhat lower cliffs on the south to Y Garn. If reasonable moel-slopes are reconstructed between the cliffs, the situation of the pre-Glacial pass would be found at a greater altitude and farther west than the present pass (at the Nantlle reservoir). By drawing a valley-profile from the pre-Glacial pass westwards, having due regard for the level at which several hanging lateral valleys are found on the way, the pre-Glacial Nantlle Valley may be roughly reconstructed. The present Nantlle Valley is several hundred feet deeper than its reconstructed predecessor.

It seems probable that a similar transection and shifting of the col at the head of the Llanberis Valley has taken place, and the depth of erosion in that case would be distinctly greater than at the head of Nantlle Valley; it may be roughly placed at 600 or 700 feet, with a widening at mid-depth of more than twice those figures.

The possibility of the overflow and destruction of a pre-Glacial divide that crossed the present valley of Afon Gwarfai where the porphyry-spur of Mynydd Mawr has been truncated deserves further consideration than can be given to it here.

XXIV. Historical Note.

It has been by intention that references to the many writers on the problem of glacial erosion have here been reduced to a minimum. It would be easy to fill page after page with citations from many European and American writers. There is abundant material in articles by the Geikies, Jamieson, Bonney, Marr, Harker, Garwood, and others in Great Britain; by Helland and Reusch in Norway; by de Margerie, de Lapparent, Kilian, Lory, and Martonne in France; by Partsch and Steinmann in Germany; by Heim, Brunhes, Früh, and many others in the Alps; by Johnson, McGee, Gilbert, Matthes, Tarr, Fairchild, and others in the United States; but there is no space left for citations in this already long paper. Yet it is only fitting that explicit acknowledgment should be made of the work accomplished by certain students of the subject to whom my indebtedness is particularly great. Mention cannot be omitted of Henry Gannett, of Washington, my class-mate of forty years ago, who, in 1898, first set forth clearly and explicitly the illuminating analogy between the hanging channels (valleys) of lateral glaciers over the deeper channel of the main glacier, and the hanging channels of lateral streams over the deeper channel of the main river; of the late Eduard Richter, of Graz, who was among the earliest to bring forth clearly the great importance of retrogressive glacial erosion in determining the form of mountain-peaks and crests that rise high over névé-reservoirs; or of Prof. Albrecht Penck, of Berlin, and Prof. Eduard Brückner, of Vienna, joint authors of that comprehensive treatise 'Die Alpen im Eiszeitalter.' Those who know the writings of these investigators will find many of their opinions in the preceding pages.

A word may also be given concerning the choice of North Wales as the field for such an investigation as is here presented. I was attracted to it by the peculiar features shown on the Snowdon sheet of the Ordnance Survey map. On the ground these features were found to be even more pronounced than the maps had indicated; they are admirably developed for field-study. There is nothing in the United States east of the Rocky Mountains that can be compared with North Wales in the way of vivid exhibition of cwms, hanging valleys, and their associated abnormal features, all the more striking because of their immediate association with normal features. The Rocky Mountains, to be sure, contain abundant examples of essentially similar abnormal features, as in the Sawatch and other ranges of Colorado, in the Big Horn range of Wyoming, and in the Front range of Montana; but all of these have the disadvantage of development on a rather inconveniently

large scale, while the glacial features in the mountains of North Wales are conveniently small and yet in every way typical. From Cwellyn Lake as a centre, nearly all the localities here described may be easily visited in four or five days.

It would be easy in describing the Welsh glacial features to adduce many similar features from other parts of the world, but it has seemed less important to multiply instances than clearly to set forth the discussion of this typical locality. The recent literature of glacial erosion may be consulted by those who wish to learn the degree of consistency with which glaciated mountains all over the world exhibit systematically associated abnormal forms.

XXV. Closing Suggestions.

Questions that have been much debated frequently leave the debaters divided into opposite parties, the members of each party remaining firm and contented in their own views. Conversion of opinion by further discussion is rarely accomplished. Recognizing this, the present essay is not particularly addressed to those who, either as glacial-erosionists or as anti-glacial-erosionists, have reached opinions definitely satisfactory to themselves by means of original investigation in appropriate fields; for the members of one of these parties would perhaps be tempted to say: 'Why elaborate so largely a matter that is almost self evident?,' and the members of the other party might perhaps say: 'How can any solid foundation for opinion be found by a method that is avowedly so full of theory?' The present essay is therefore addressed to those of a younger generation who have still to form an opinion as to the manner in which glaciated mountains have been sculptured, who wish to examine both sides of the question, and who desire to be self-responsible in forming their opinions. It is hoped that to readers of this class the preceding pages, in which an impartial examination of both theories has been attempted, may prove of some assistance.

XXVI. Bibliography.

Citations in the foregoing pages refer by author, date, and page, to the following memoirs:—

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EXPLANATION OF PLATE XIV.

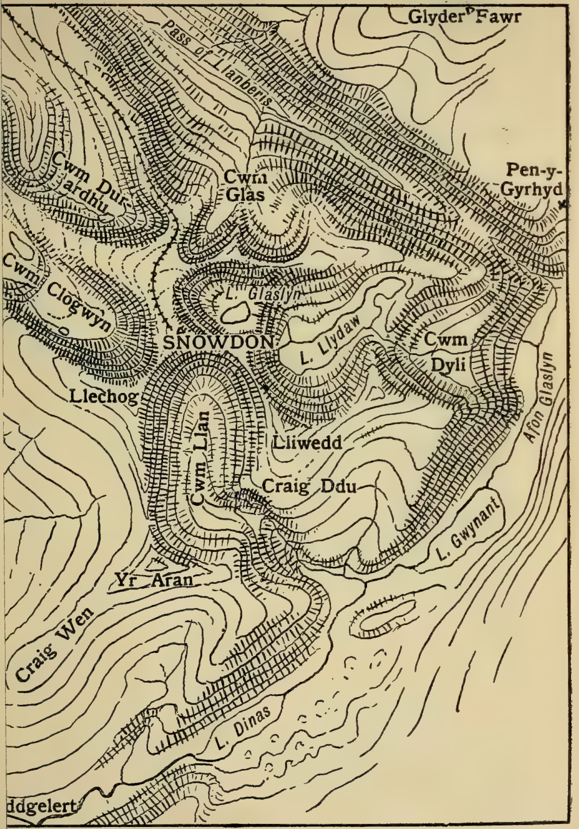
Outline-map of the Snowdon district, on the scale of approximately 1: 70,000.

Discussion.

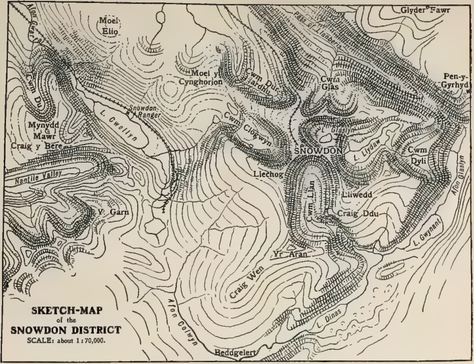
Dr. Marr stated that, as the result of the Author's instruction in the English Lake District (presenting features so similar to those in the area described in the paper), he was bound to acknowledge that he (the speaker) had greatly under-estimated the effects of glacial erosion. He referred to Mr. Alfred Harker's papers in the 'Geological Magazine' for 1899 and the Trans. Roy. Soc. Edin. 1901, as giving views similar to those advocated by the Author. He no doubt spoke the feelings of all present, when he expressed his pleasure at hearing so luminous a paper from the Society's distinguished Foreign Correspondent.

Mr. T. Crook remarked that the Author had compared the hypothetical pre-Glacial relief of the Snowdon group with certain subdued and much rounded types to be seen in Carolina and elsewhere. He would like to ask what type of rock and structure prevailed in the subdued mountain-system of Carolina to which the Author referred in making this comparison. He raised this question, because it was obviously important that, in framing assumptions as to any probable former type of relief in a mountain-system, the influence of rock-variety and structure as determining factors should be considered. In stating the character of what he termed a normally subdued and non-glaciated type of relief, the Author apparently ignored these factors. As bearing on this point, the speaker further asked whether an actual example could be given of a mountain-system, having the Snowdonian type of rock and structure, which had, under similar climatic conditions, developed a relief resembling that which the Author had assumed to exist in the Snowdon group during pre-Glacial times.

M. M. Allorge said that he had been charmed by the lucidity of the Author's description of the Snowdon district and by his series of skilful diagrams on the blackboard, conveying so vivid a sense of the three dimensions, and illustrating the morphological



'; *for* Cwm Dur-ardhu' *read* 'Cwm Dur-arddu'.]



[*For* 'Pen-y-Gyrhyd' *read* 'Pen-y-Gwrhyd', *for* Cwm Dur-ardhu' *read* Cwm Dur-arddu'.]

evolution of that area. The three following features were considered by the speaker as characteristic of glacial erosion:—(1) the cirques; (2) the steps interrupting the valley-floors; and (3) the lake-basins. Besides these three features, there were two other kinds of land-forms of equally frequent occurrence in glaciated regions, and, as the speaker had been often puzzled by their origin, he would like to take that opportunity of asking the Author to apply his deductive method to the explanation of the origin of the following two classes of abnormal features:—(1) The isolated knobs occurring here and there in glaciated valleys had already been referred to by the Author as truncated spurs of a former river-valley. This ingenious explanation, although correct in many cases, did not seem applicable to all the instances. Would it be correct to consider some of the knobs as the result of the remarkable way in which the ice eroded differentially according to the hardness of the rocks? If this were the case, some of these knobs would be merely the giants of the 'roches moutonnées,' or, to put it in a more up-to-date way, 'monadnocks of glacial origin.' (2) Transverse rock-barriers or 'riegel' were known to stretch frequently across glaciated valleys. In Switzerland some of the most notable of these barriers had a tendency to occur near the junction of two different formations: for instance, both the transverse barrier near Meiringen and that near St. Maurice (Valais) were formed of Mesozoic limestones, and stood close to the junction with the crystalline rocks. Both were cut by a narrow gorge which seemed to be the result of subglacial water-erosion, because no terraces and no other indications of a temporary lake were to be found above these barriers. At all events, the Author was perhaps inclined to carry a little too far 'the indifference of topographic form to the trend of formation-boundaries,' in order to reduce every type of scenery to a simple formula where the three ratios worth considering according to him were: (i) the structure; (ii) the agencies at work; and (iii) the stage of the cycle. The speaker was tempted to continue to think that the nature of the rocks was worthy of equal consideration, even from a mere geographical standpoint, as introducing into the landscape a specific characteristic of its own.

With regard to the term 'geographical cycle,' frequently used by the Author, 'cycle' always suggested to the speaker the idea of a complete circle, of a return to the primitive state of things. As this was not exactly the case in geomorphogeny, where the final peneplain was not entirely comparable with the original structural surface, perhaps it would be more accurate to speak of the 'evolutive stages of erosion.'

The Rev. E. C. Spicer, referring to glacial cirque-formation, quoted the 'Journal of Geology' (Chicago) for 1904, vol. xii, p. 569, where Dr. Willard D. Johnson gave an apparently satisfactory explanation of the phenomena.

Dr. A. P. Young said that it might be interesting to recall the

suggestions made many years ago by Prof. W. Salomon regarding a possible mode of ice-erosion. The changes of pressure following on the movement of the ice bring about variations in the freezing-point of water, and corresponding alternations of frost and thaw. By this means the rock is attacked along clefts and joint-planes, and detached fragments are carried forward in the flow of the ice.

As regarded the formation of cwms and corries, the speaker noted that the independent glaciation of this region required during the greatest cold a snow-line very much below the highest ridges and summits. The hill-slopes above this level carrying firn only, escaped ice-erosion. As the snow-line rose during a retreat the glaciers broke up into smaller tongues, and higher surfaces came under the action of ice. It was thought not improbable that small corries had been excavated by the action of short tongues of ice, which formed when the snow-line persisted at a level much higher than that at which it stood during the period of maximum glaciation, and after the retreat of the ice from the larger valleys.

Prof. W. W. Watts agreed that the pre-Glacial form of Snowdon, which the Author had restored with great skill, was probably correct, as was indicated not only by the form of mountains on the west but also on the north-east. The real difficulties of the question had not been solved by the Author. These were (i) the steep heads of the cwms, (ii) the steps of the cwms, and (iii) the existence of lakes both in cwms and valleys. If the steep cwm-heads were due to frost, glaciers may have acted by transporting; but the speaker believed that frost work might go on under a considerable depth of scree, such as the Author believed to be now filling up the cwms. If the 'steps' were due to cutting back at some point of rock-difference, such difference ought to be still observable, and the Author had proceeded on the statement that such differences were now ineffective. As to lakes, if a glacier were steadily scouring a valley down, every movement, whether upward or downward during the epoch of glaciation, would result in the formation of a lake; such movement in complicated rock-structure would not necessarily be recognizable by its effect on structure.

Prof. Garwood wished to associate himself very heartily with Dr. Marr in welcoming the Author to a meeting of the Society, and congratulated the Fellows on the opportunity that had been afforded them of listening to a most interesting communication. He thoroughly agreed with the Author that the assemblage of features described were essentially characteristic of glaciated countries; but, while never doubting that ice was an erosive agent, he had found it difficult to account for certain features in the Alps by simple differential ice-erosion, and had been driven to consider the possibility of differential erosion as between ice and water. Was it not possible that ice, being relatively a protective agent, might have retarded the erosion of those portions of the surface on which it still remained after it had retreated from other parts of the district? The speaker referred to such cases as the Albigna Valley below the Maloja Pass, which was still occupied by a large glacier,

and pointed out that this was one of a row of glaciers still occupying valleys which faced north-east, whereas no corresponding glaciers or hanging valleys were found on the other side of the Inn Valley, and the same feature was noticeable, as he had pointed out, in the Ticino Valley and in Sikhim. Two other features, namely, the marked step which occurred near the head of many of the main valleys and those which often occurred far back in the lateral hanging valleys, seemed unaccountable on the hypothesis of simple glacial erosion; whereas, if glaciers are regarded as relatively protective agents as compared with rivers, these steps would represent the surface which had been relatively protected as the glacier retreated, while the valley below was being deepened by water-erosion. Such relative difference of erosion could be actually seen in the gorges cut by subglacial streams. With regard to the origin of cirques, alluded to by several speakers, this, again, seemed a case where relative protection by ice might have taken place by the accumulation of avalanche-snow on the floor of the cirque while the sides were being eaten back by frost and weathering, so that the snow accumulated farther back each year. A certain amount of erosion, however, took place, as explained by the bergschrund hypothesis alluded to by a previous speaker; but, on the whole, the effects of a corrie-glacier appeared to be relatively protective.

The PRESIDENT (Prof. SOLLAS) congratulated the Author on the successful manner in which he had rejuvenated a mildly-matured subject. His essay was an extremely consistent piece of deductive reasoning, and it was almost impossible to restrain a feeling of resentment towards the difficulties which presented themselves when parts of the argument were brought into relation with existing facts of detail. It was to be hoped that in his reply to criticisms, especially those of Prof. Garwood, the Author would be able to maintain the symmetry of his system in all its parts.

The AUTHOR said that, owing to the lateness of the hour, it was not possible for him to comment fully on the questions and suggestions made by the several Fellows who had remarked upon his communication.

Regarding the contrasted forms of valleys, as seen in cross-profile, it was well to note that a mature valley of normal erosion might sometimes imitate what was called the U-shaped valley of glacier-erosion; that the V-shaped valley of normal erosion was only a young normal valley; and that many maturely glaciated valleys had not a U-shaped but a catenary cross-profile: the U-shaped glacial valley or trough was a young glacial trough, in which deepening had been more active than widening.

The Author was very glad to leave the Lake District in Dr. Marr's hands, and looked forward with pleasure to his further account of it. He begged leave to point out that what characterized his paper was not so much the views to which it led, as the attempt to provide a thoroughly discussed basis for these views, and thus to make them fully worthy of acceptance.

As to the influence of structure on relief (regarding which

Mr. Crook raised a question), structure was of fundamental importance: it was the first term in the systematic method for the description of land-forms in terms of 'structure, process, and stage', with which the Author was experimenting. But the influence of structure decreased with the advance of the cycle of erosion, and in late maturity, when the surface became covered with creeping waste, structure had relatively small value, unless strongly contrasted hard and soft rocks were present. The subdued mountains of North Carolina, to which he (the Author) had referred as types of normal late mature forms, were composed chiefly of crystalline schists. He believed that a comparison might fairly be made between these mountains and the subdued pre-Glacial mountains of Wales.

Prof. Watts and several other speakers enquired as to how an eroding glacier could produce cwms, lake-basins, and valley-floor steps. As to cwms, the detachment of rock-blocks by freezing and thawing of water in the bergschrund around the head of a glacier, as suggested and observed by Dr. Willard D. Johnson, was certainly an effective process so far as it went; but it did not go deep enough. The deepening of the broad cwm-floor required another process, and of all suggestions, the Author thought frictional dragging or plucking was of most value. It might be aided by freezing and thawing of water in joints, due to changes of pressure instead of to changes of temperature, as had been pointed out by several geologists. The production of valley-floor steps and basins was a necessary corollary of glacial erosion. The transformation of a mature pre-glacial valley into a mature glacial trough must be gradual: during its progress, the deepening of the trough-bed must be somewhat irregular; steps and basins were a most likely result, wherever any differences of structure occurred. The Author would be glad to hear a fuller explanation of Prof. Watts's statement that every earth-movement in a glaciated district was 'registered as a lake': surely a general uplift along the mountain-axis, whereby the slope of a glacier must be increased, would not be so registered; neither would a local up-faulting of the upper end of the glacier-filled valley produce a lake; nor would a warping of the valley produce a lake, if the glacier wore down the up-warped part of the valley.

The Author differed from Prof. Watts as to the real difficulties of the question. The explanation of steps and basins in cwms and valleys offered no special difficulty, if it were once proved that glaciers erode their troughs; for, in that case, some inequality of trough-erosion was as likely as in the erosion of a channel by a river. Differences of structure sufficient to cause basins and steps might be perceptible to an eroding glacier, even if not perceptible to an observant geologist. The real difficulty therefore was not in the explanation of minor features, such as basins and steps, but in the process of general glacial erosion, of which basins, steps, and various other features were necessary and reasonable corollaries.

The cwm-head cliffs, however, were serious difficulties under any theory yet proposed.

The British preference for British terms might be set against the preference of German geologists for German terms, of French geologists for French terms. Geology and geography were properly international subjects, and the Author's own preference was therefore for an international terminology. He was sorry to learn that the Welsh term, crib, is pronounced creebe, for it was thereby unfitted for general use in its original spelling.

The transverse bars in glaciated valley-floors, mentioned by M. Allorge, were features to be expected; they must be produced in a glacial trough, eroded in structures of unlike resistance, but not so maturely eroded as to be well smoothed. The steep slope on the up-stream side of some of these bars was a puzzling feature. Rock-knobs were also, the Author believed, to be regarded as marking immature troughs: had glacial action lasted longer, the trough would have been better smoothed. The objection to the term cycle had been often raised. It did not seem important, because a well-recognized meaning of the word was a long period of time. But it might be pointed out that 'cycle,' as indicating a series of changes that ended about as they began, was very appropriate for plains and plateaux; and hardly less so for those many mountains which had been eroded from uplifted peneplains, for in the end they would have essentially the same form as in the beginning. M. Allorge's suggestion that it was going too far to speak of 'the indifference of topographic form to the trend of formation-boundaries' was aside from the point. This statement was not a general theory, but a local induction from observation in the Snowdon district. The further suggestion that this statement resulted from an effort to reduce every type of scenery to a simple formula revealed an unexpected failure on M. Allorge's part to understand the Author's meaning. 'Nature of rocks' was included under 'structure,' and was considered as a matter of course; but, around Snowdon, all the rocks were of so resistant a nature, that their influence on form was of secondary importance. It was perceptible, however, in certain rock-steps.

The example of the steep-headed Maira Valley, southward from the Maloja Pass, in connexion with the hanging lateral valley on its eastern side, pointed out by Prof. Garwood, could not be satisfactorily explained by normal erosion, for the recession of such a valley-head by normal erosion was extremely slow; and, while the valley-head was receding, the side-valley must have been cut down to grade with the main valley-floor. It was simply inconceivable that a relatively protective glacier could have held its end at the mouth of the side-valley during all the time required for the recession of the valley-head by normal erosion. The explanation for these features, as first suggested by Heim, needed revision, in view of the possibility of glacial erosion. The explanation of certain hanging valleys in the Himalayas by the process of river-capture

was not convincing: not because the process of river-capture was unreal or ineffective, but because the various consequences that must accompany such a capture were not clearly deduced and compared with the appropriate facts. Until such deduction and comparison was made the explanation remained uncertain. The difficulty that Prof. Garwood found in accounting for small branch-valleys that hang over hanging lateral valleys was not a difficulty in the theory of glacial erosion; it was, indeed, an expectable and essential consequence of that theory, for the relation of the branch-valleys to a lateral valley was the same as the relation of the lateral valleys to their main valley. It was to be noted that, in Prof. Garwood's favourable consideration of the protective action of glaciers as a means of accounting for hanging lateral valleys, he had taken no account of the various difficulties which stood in the way of accepting that explanation. Until these difficulties were considered and set aside, the Author found it difficult to accept the theory that glaciers were protective agents. The explanation of cirques by protective ice and snow involved assumptions as to the action of weathering in the steepening of the cirque-head cliffs; and these assumptions had not been sufficiently examined and justified.

19. *The* Nephrite *and* Magnesian Rocks *of the* South Island *of* New Zealand.

By Alexander Moncrieff Finlayson, M.Sc., A.O.S.M. (Communicated by Prof. W. W. Watts, Sc.D., F.R.S., V.P.G.S. Read April 28th, 1909.)

[Plates XV & XVI—Microscope-Sections.]

I. Introduction.

Ever since Hochstetter's work on the olivine-rock of the Dun Mountain, and on the New Zealand nephrite or 'greenstone,' the rocks of the 'magnesian belt' of the South Island of New Zealand have had an absorbing interest for students of that district. The term 'magnesian belt' is here used to denote those peridotites and serpentines that have hitherto been frequently referred to by the names 'serpentine-belt' and 'mineral-belt.' Until recent years, however, the occurrence and nature of the various exposures which comprise this most interesting and significant petrographic province have remained rather obscure, owing to the rugged nature of the country and the inaccessibility of the chief localities.

In this paper is given a general account of the peridotite- and serpentine-rocks of the South Island and a discussion of the nature and origin of New Zealand nephrite. Those analyses which are not attributed to others are my own work, and were made in the geological laboratory of the Imperial College of Science & Technology, South Kensington.

II. The Peridotites and Serpentines.

General Occurrence and Relations.

Occurrence.—The position of the known outcrops is indicated on the map accompanying this paper (fig. 1, p. 352). The magnesian belt, as generally understood, first appears as a group of serpentines and peridotites extending from D'Urville Island in a south-westerly direction for some miles past the town of Nelson. Serpentines have also been observed in the Buller basin; and still farther south, in the western foothills of the Southern Alps, occur the disconnected sills and dykes of serpentine and talc-rocks in the Teremakau and Hokitika basins: these intrusive rocks are the matrix of the nephrite. Large massifs of peridotites compose the Olivine and Red-Hill ranges in North-Western Otago, while a group occurs at Anita Bay (Milford Sound) and another at the Cow Saddle, north-west of Lake Wakatipu. Isolated outcrops of serpentine-rocks, occupying a detached position with reference to this main belt,

occur near Collingwood and in the basin of the Takaka River in Nelson Province, at Gibbston in Central Otago, and west and south of Lake Wakatipu.

The localities which have been specially examined in connexion with this paper are those at Parapara, Dun Mountain, Gibbston,

Fig. 1.

and on the Griffin Range (Westland). For specimens of the rocks at the Cow Saddle and Milford Sound I am indebted to Prof. P. Marshall, and for rock-specimens from the Hokitika watershed to Mr. P. G. Morgan, of the New Zealand Geological Survey.

Relations.—The correlation of these different exposures into a petrographic province the members of which are approximately contemporaneous is, in the present state of our knowledge, somewhat premature, although it is generally agreed that the occurrences extending from D'Urville Island to the south of Lake Wakatipu comprise such a unit. The exact relations of the Milford Sound group are still *sub judice*; while the inclusion with the rest, of the Collingwood and Gibbston occurrences, is purely arbitrary. The evidence for the contemporaneity of all these intrusions will be summed up later. At present it may be pointed out that the case for contemporaneity rests on petrographic similarity; on the linear distribution of the whole series; and on the fact that, wherever carefully examined, the rocks are found to be intrusive into Mesozoic and Palæozoic sedimentaries, although these sedimentaries vary considerably in age.

Previous Geological Work.

The first worker on these rocks was Dr. F. von Hochstetter, who, in 1859, examined the rocks of the Dun Mountain district, Nelson [1].[1] Then followed Sir James Hector, whose explorations in the western Sounds in 1863 made known the locality of bowenite [2]. Since then the peridotites and serpentines in various districts have been located during the reconnaissance-surveys of Prof. James Park in Collingwood County [3] and North-Western Otago [4], of Prof. S. H. Cox in the upper Buller district [5], and of Mr. A. McKay in Westland [6]; while E. H. Davis in 1870 described the rocks of the Dun Mountain district [7]. In the last three years Dr. J. M. Bell has greatly increased our knowledge of these rocks in the Hokitika [8] and Collingwood [9] areas, and the monograph of Prof. Sollas on the rocks of the Hauraki goldfields [10] contains also descriptions of rock-specimens from the Hokitika district (pp. 185 *et seqq.*). Further, short accounts have been published of the deposits of copper [11] and chrome-ores [12] in the serpentines at Nelson.

Of other than official geologists, G. H. F. Ulrich described the peridotites of the Olivine and Redhill ranges, and the associated nickel-iron alloy awaruite [13]. F. W. Hutton described some of the Nelson and Western Otago rocks [14]. Lastly, Prof. P. Marshall has given valuable accounts of the rocks from the Cow Saddle [15] and Anita Bay [16], and of the gabbro of Dun Mountain [17]. To Dr. F. Berwerth we owe the identification of the bowenite of Anita Bay [18].

[1] Numerals printed in square brackets refer to the Bibliography, § IV, p. 378.

Description of Special Areas.

(1) Parapara.

This occurrence, which has been described by Dr. Bell [9, p. 66], consists of a group of talc-serpentine rocks cropping out in the gorge of the Parapara River, 7 miles south of Collingwood township. The rocks are generally much foliated, indicating a high degree of dynamic metamorphism, and contain a good deal of magnesite and grains of chromite. The serpentine occasionally contains residual grains of olivine, but is more usually of the laminated type, showing under the microscope a fairly typical antigorite-structure. There is no evidence as to the particular mineral from which the antigorite has been derived, and it appears to be essentially the result of great pressure.

Effects of contact-metamorphism caused by the intrusion consist in the development of corundum crystals, and more notably of tourmaline in the surrounding schists [9, p. 67]. The tourmaline crystals are of varying size, the average length being half an inch; but occasionally they are very coarse, measuring as much as an inch in width and 8 or more inches in length. The smaller crystals occur grouped in roughly radial fashion; while the larger show a remarkable cross-fracture, repeated along their length, and imparting to the crystals often a stepped appearance. The effect is evidently a result of considerable pressure on the less resistant rock which contains them. The colour of the crystals is dark green to black, and the following analysis indicates an iron-magnesia variety:—

SiO_2	36·80
B_2O_3	10·41
Al_2O_3	25·37
Fe_2O_3	0·13
FeO	6·12
CaO	2·31
MgO	12·91
Na_2O	1·20
K_2O	0·45
Li_2O	trace
H_2O	3·95
F	trace
Total	99·65

Under the microscope (Pl. XV, fig. 1), the tourmaline-bearing rock is seen to be composed of coarse elongated crystals of tourmaline and bunches of granular magnetite in a matrix of foliated chlorite with some serpentine. The chlorite folia are distorted in passing round the included crystals of tourmaline and magnetite, imparting to the rock an 'augen-structure.' The pleochroism of the tourmaline crystals is pink to bluish-grey, with strong absorption. Good octagonal cross-sections are sometimes seen, which show a corroded and altered centre, with separation of secondary magnetite.

Longitudinal sections show further the cross-fractures which are so marked in the hand-specimen.

It appears that we are here dealing with a differentiated intrusion of peridotites, which were accompanied by emanations of boron compounds, an unusual feature in this class of rock. Hydration of the minerals has occurred, followed by considerable dynamic stress, which has left its effects on the tourmaline crystals and on the more foliated portions of the intrusion. There is no doubt, then, that the intrusion antedates the period of general metamorphism of the surrounding schists and quartzites.

(2) Dun Mountain.

The rocks here described consist of an intrusion 6 miles south of the town of Nelson, having an average width of 3 miles. The intruded rocks are indurated breccias and red and green slates on the south-east side, and Maitai limestones and slates on the north-west. The former have been classed as Devonian and the latter as Carboniferous [19]; but for this correlation there is scant evidence, and the recent researches of Prof. Park indicate that the rocks are of either Triassic or Jurassic age [20]. The boundary of the magnesian rocks is particularly well marked by the sudden change from thick bush on the calcareous slates and limestones to bare tussock-covered or rocky slopes when passing on to the serpentines and peridotites. The description of two sections across the intrusion will indicate sufficiently the character of the rocks.

Section 1 (Aniseed Valley).—In this line of section (fig. 2, p. 356) the Maitai rocks on the north-west side, striking north to north-east, and standing vertically or dipping very steeply away from the intrusion, are dark slates of varying texture, with bands of limestone bordering the intrusion. The limestones are succeeded by a belt from 50 to 100 yards wide of a mottled rock composed, as Prof. Marshall has pointed out, of the lime-garnet grossularite with diallage, and evidently formed by contact-metamorphism of the limestone. Passing up the valley, this contact-zone is succeeded by a wide belt of rocks composed largely of serpentine, either dark and massive or paler and foliated. The former variety is veined with fine chrysotile, while the leek-green foliated belts of serpentine carry occasional picrolite (columnar serpentine) on selvages. Associated with the serpentine are bands of pyroxenite (diallage-rock) of all degrees of coarseness, and small veins of saussurite-gabbro, highly serpentinized olivine-gabbro, and dunite. Veins of both grossularite and wollastonite occur as products of contact-metamorphism, scattered through the serpentine; and a prominent belt of copper and other sulphide-ores occurs in the serpentine near the contact-zone. On the other side of the intrusion the serpentine

Fig. 2.—*Diagrammatic section across the peridotite-belt, Aniseed Valley.*

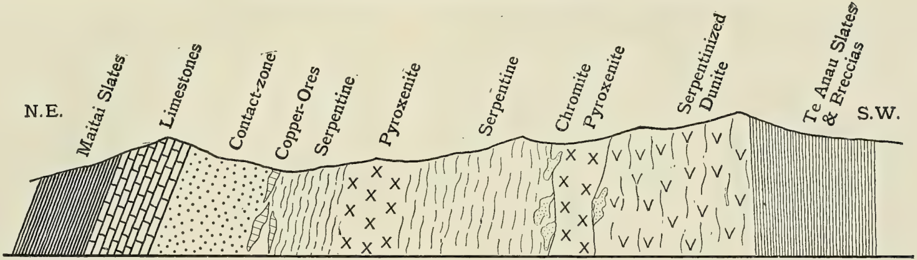
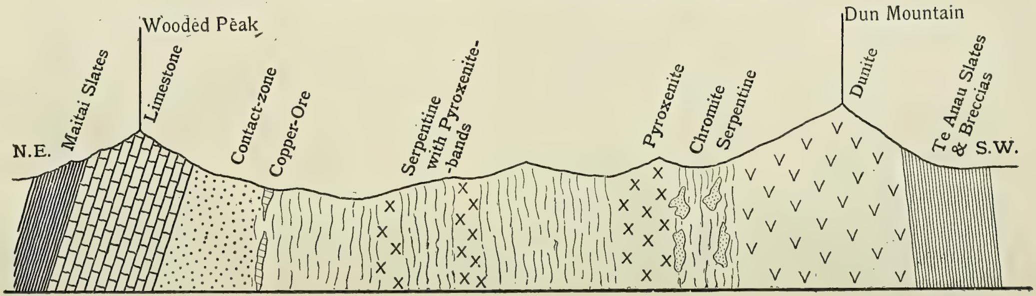


Fig. 3.—*Diagrammatic section across the peridotite-belt, Dun Mountain.*



passes gradually into a serpentinized dunite; but fresh dunite does not appear in this section, which is closed by the tough red slates and breccias of the Te Anau Series.

Section 2 (Dun Mountain tramway).—This tramway, which was built many years ago to convey into Nelson the chrome-ore from the workings on the Dun Mountain, gives an excellent section (fig. 3, p. 256). The slates pass down into a fairly broad band of limestones, which pass gradually, as before, into the garnet-pyroxene rock of the contact-zone, carrying occasional included masses of baked and indurated slates. This is succeeded by the wide serpentine belt, with irregular inclusions and veins (in its western portion) of garnet-rock and of wollastonite. After about 2 miles, the serpentine is succeeded by a coarse pyroxenite, with associated saussurite-gabbro and garnet-gabbro. Chromite occurs segregated conspicuously in the neighbourhood of the pyroxenite, where it was mined to some extent in former years. Then follow serpentines and pyroxenites bordering the olivine-chromite rock or dunite. This latter occupies an apparently isolated area of about half a square mile on the summit of the Dun Mountain, where it weathers with the formation of a thick reddish crust; but coarse scree-deposits give it the appearance of having a much more extensive outcrop. Towards the north-west it sometimes passes by degrees into serpentine, and at other times it is succeeded by pyroxenite with scarcely any marginal variation. The dunite is bordered on the south-east by the Te Anau Slates.

Davis believed that the dunite was intruded later than the mass of the serpentines [7, p. 117], but the evidence adduced by him in support of this is inconclusive. On the other hand, the gradual passage which can be traced in places from fresh dunite into serpentine is strong evidence that the whole series forms a contemporaneous differentiated complex.

Petrography of the Intrusive Rocks.

Dunite (Pl. XV, fig. 2).—This rock has been described by previous workers [14, pp. 154–55]. The associated chromite occurs as segregations of fairly pure ore, chiefly along the margins between the dunite or serpentine and the pyroxenite. Microscopic examination shows that chromite was the first constituent to separate out during rock-differentiation. It is worthy of note that this mineral also occurs, in places, embedded in the garnet-rock of the contact-zone.

Serpentine.—The massive serpentines show all stages in the alteration of olivine, though generally the rocks are serpentinized and veined intricately with secondary chrysotile. The more foliated serpentines show microscopically the finely laminated

structure and occasionally the typical thorn-structure of antigorite. There is no evidence of derivation of the antigorite from pyroxene, and this variety appears here to be due chiefly to pressure and movement along shear-zones in the serpentine mass.

Pyroxenite.—This rock, when fresh, consists of cleavage-slabs of colourless or pale yellow diallage (often very coarse). Brown patches of schillerized inclusions are frequent, and the formation of bastite is often noticeable.

Serpentine-pyroxenite.—This type is an altered peridotite, containing serpentinized olivine and colourless diallage. The diallage occasionally shows marked uralitization, the crystals having a broad selvage of fibrous amphibole with an extinction-angle of 16° to 19°. Some bastite in the rock may represent original enstatite.

Gabbro.—This rock, which occurs only in small veins, consists of saussurite and uralite. The original plagioclase, of which a few hazy outlines may sometimes be seen, has been almost completely altered into a fine-grained aggregate of saussurite. The hornblende is a pale green variety, occurs plentifully in rectangular or irregular plates, and occasionally encloses cores of original pyroxene. At other times the octagonal cross-section of augite has been preserved in the hornblende.

Petrography of the Contact-Zone.

Garnet-pyroxene rock (Pl. XV, fig. 3).—This type, the syenite of Davis [7, p. 115] and the saussurite-gabbro of Hutton [14, p. 146], has been shown by Prof. Marshall to be a rock composed of diallage and grossularite-garnet [17, p. 321]. As the last-named writer has pointed out, it is highly probable that both the garnet and the wollastonite mentioned above represent portions of limestone that have been caught up and digested by the peridotites in their ascent.

Epidote-rock (Pl. XV, fig. 4).—This variety, which passes gradually into epidote-serpentine rock, occurs as included lenticles in the serpentine in association with the copper-ores along the limestone margin. It is grey to straw-yellow in colour, and contains veinlets and grains of chalcopyrite. In section it shows a mass of epidote in needles and columnar crystals, thickly interlaced. These are set in a ground-mass of fibrous serpentine and of finer epidote-needles, which latter are only resolvable under a high power. The epidote is pale yellow or colourless, and the following analysis of carefully selected material shows it to be a lime-variety:—

SiO_2	42·45
Al_2O_3	23·27
Fe_2O_3	7·91
FeO	1·22
CaO	21·52
MgO	1·45
H_2O	2·62
Total	100·44

Serpentine-amphibole rock (Pl. XV, fig. 5).—This type, which also occurs in lenticles in association with the ores, is dark greenish grey in the hand-specimen, and consists of a moderately hard serpentine, veined by a massive grey mineral of considerable hardness (6 to 7). Under the microscope this latter appears as numerous branching and intersecting veins of a grey-brown, slightly pleochroic mineral, which is resolved between crossed nicols into a mass of tufted and sheaf-like fibres exhibiting bright interference-colours of the second order and a maximum extinction-angle of 15°. A separation and analysis was made, with the following result, indicating an amphibole:—

SiO_2	48·20
Al_2O_3	1·35
Fe_2O_3	4·67
FeO	10·96
CaO	12·62
MgO	19·58
K_2O	0·66
H_2O	1·43
Total	99·47

It is thus evident that we are dealing here with a fibrous amphibole, which appears to have been formed by interaction between the limestone and the intrusive magnesian rocks.

Sulphide ores.—These are chalcopyrite and pyrrhotite, which occur as lenticular bodies along and near the contact-zone in the serpentine. Mining operations have shown that chalcocite and native copper occur as secondary ores above the groundwater-level, occasionally in large bunches. Malachite and chrysocolla are conspicuous near the surface. The origin of the primary sulphides may be provisionally referred to contact-metamorphic action.

Conclusions.—The magnesian rocks of the Dun Mountain district consist of a differentiated series of peridotites intruded into Mesozoic slates and limestones. Processes of hydration, which appear to have been concentrated chiefly in the neighbourhood of the belt of sulphides, and to have acted with diminishing intensity towards the other side of the intrusion, have resulted in the serpentinization of the olivine-rocks, with the exception of the

residual mass which composes the summit of the Dun Mountain. Subsequent alterations, due to dynamic agencies, have resulted in the development of uralite, saussurite, and antigorite.

(3) Hokitika Area.

The magnesian rocks of this district consist of disconnected outcrops of serpentine and talc-rocks representing sills and dykes of peridotites intruded into the mica-schists on the western side of the Alpine watershed. They have been traced from the Teremakau River in the north to the upper waters of the Hokitika River in the south, occurring, for the most part, in very rugged and inaccessible country. They have been mapped and described by Dr. Bell & Mr. Fraser [8, p. 67].

Speaking generally, it may be said that the intrusives show two well-defined types—(*a*) massive serpentine-rocks and (*b*) serpentine-talc-carbonate rocks, the two types occurring in distinct and separate outcrops. The latter type, but not the former, is the matrix of the nephrite. The serpentines occasionally show a mesh-structure, and a fresh dunite has been described from the Hokitika gorge [10, p. 193]. Antigorite-serpentine, with typical thorn-structure, occurs to a notable extent, as first pointed out by Prof. Bonney [21]; and the same authority has described specimens from the upper Hokitika watershed, which show very strikingly the development of antigorite from augite. Specimens from Captain Jack's Spur, given to me by Mr. P. G. Morgan, also show augite granules pierced irregularly by needles and flakes of antigorite.

The contact-effects of the intrusive rocks, with the striking development of lime-magnesia silicates and the occurrence of platiniferous quartz-veins in the vicinity genetically related to these rocks, have been fully described by Dr. Bell & Mr. Fraser [8, p. 70]. Here, as at the Dun Mountain, there is evidence of considerable hydrothermal action accompanying the intrusions.

(4) North-Western Otago.

The peridotites of this district occupy a large area. They were described by Ulrich [13] from specimens supplied by explorers. He distinguished two types of olivine-enstatite rock, one occurring in the Red Hill Range, the other in the Olivine Range. These peridotites are the matrix of the peculiar nickel-iron alloy awaruite ($FeNi_2$), which occurs commonly in the sands of the Awarua and neighbouring rivers.

(5) Cow-Saddle Area.

This interesting group of rocks has been described by Prof. Marshall [15]. The rock-types in succession from east to west are dunite, lherzolite, pyroxenite, gabbro, and diorite, thus showing a progressive change in basicity. The rocks are, on the whole, much too

altered to be of value for chemical analysis. As may be seen in the descriptions of the rocks by Prof. Marshall [15], the characteristic alteration-products are serpentine from olivine, saussurite from plagioclase, and bastite and uralite from pyroxene. Prof. Van Hise has pointed out that hornblende appears to be more stable than pyroxene under moderately deep-seated conditions of metamorphism [22], and his conclusions are fully borne out by the modes of alteration of the pyroxene-bearing rocks described in this paper. The uralitization of pyroxenes is a constant and characteristic phenomenon in the New Zealand peridotites.

(6) Other Occurrences in Western Otago.

The serpentine-talc rock near Gibbston has been described by Prof. Park [23] and by the present writer [24]. The serpentine-rocks on the Caples River west of Lake Wakatipu, and in Windley Creek south of the same lake, are of a similar nature. The serpentine of the latter locality contains a good deal of pyrite in places.

(7) Milford Sound Area.

At Anita Bay there occur dunite, hartzbergite, and a peculiar talcose rock, all enclosed in highly-contorted gneissic granulite. The talc-rock is the matrix of the interesting species bowenite. The dunite and hartzbergite have been described by Prof. Marshall [16, pp. 482–83]. It is worthy of note that the dunite shows a pronounced cataclastic structure, and that the enstatite of the hartzbergite reveals all stages of alteration into magnesite, the final product being an olivine-magnesite rock which closely resembles a marble in hand-specimens. Prof. Marshall has suggested that the effect may be due to the solvent action of percolating waters charged with organic salts derived from the dense vegetation which clothes the hillsides [16, p. 483]. The olivine is in all cases perfectly fresh.

Bowenite.—This mineral, the tangiwai of the Maoris, occurs in irregular veins and seams ramifying through its matrix (to be subsequently described, p. 362). The hand-specimen is generally of a sea-green or olive-green colour, best seen when polished. It is, when pure and free from flaws, highly translucent, and, owing to its hardness, takes a very fine polish. Being softer than nephrite, it is less suited for weapons or tools, and hence was little used by the Maoris. Its translucency, however, is generally superior to that of 'greenstone,' and reflections due to cloudy and scattered inclusions impart to it often a very handsome appearance. It was, indeed, the most beautiful of the stones known to the Maoris, and the one least valued by them.

The mineral is massive and scaly or fissile in structure, and its hardness varies greatly according to the surface on which it is tested. On fissility-planes it varies from 3 to 4 (Mohs's scale). On surfaces cut at right angles to these planes it averages 4·5, while

on polished faces in the same direction its hardness is 5 to 5·5, amounting at times to 6.

Under the microscope (Pl. XVI, fig. 1) it is seen to consist of a colourless aggregate of dense serpentine-fibres, of almost ultra-microscopic fineness, arranged in wavy or corrugated laminæ and showing aggregate polarization. The laminæ, when examined under a high power, are seen to be much plicated and sheared, forming a felted mass. This microscopic structure evidently explains the great hardness and toughness of the mineral, exactly as in the case of nephrite. The mineral is optically negative, like antigorites or laminated serpentines; but it does not show the structure of antigorite derived from augite, as has been described by Prof. Bonney in the case of the Afghanistan bowenite [21, p. 169].

It contains small included aggregates of magnesite and patches of infiltrated ferric oxide, these two constituents being the cause of the striking sheen and colour-effects seen in prepared specimens. Small grains of chromite are also frequently present, and Ulrich has recorded bowenite from the Cascade River containing grains of awaruite [13, p. 629]. The whole structure, as seen under the microscope, gives emphatic proof of intense dynamic effects in the formation of the mineral. A few residual flakes of talc occur, in places, scattered through the mass of the mineral. The following analyses indicate its composition:—

	I [18].	II [25].	III [25].		IV [25].
SiO_2	44·77	40·20	41·20		45·91
FeO	3·35	12·10	12·10		1·67
MgO	39·17	33·20	34·02		35·07
H_2O	12·94	12·70	12·94		12·67
Totals ...	100·23	98·20	100·26	Al_2O_3...	5·63
					100·95

Nos. II, III, & IV contain traces of MnO and Cr_2O_3.

Specific gravity = 2·61.

The Anita Bay mineral is very similar, petrographically and chemically, to the original bowenite from Smithfield, Rhode Island [26], and to that from Afghanistan described by the late General McMahon [27].

Bowenite matrix.—This rock, which contains the bowenite-veins, has a greyish-green colour in the hand-specimen, with a scaly structure and soapy feel, and a hardness which varies from 1·5 to 4.

Under the microscope, it is seen to consist of coarse plates of talc, generally much shattered and crushed, surrounded and veined with magnesite and finely-laminated serpentine clearly derivative from it (Pl. XVI, fig. 2). The talc has a foliated structure, and

most specimens show little or no serpentine. Slides cut from specimens which contain bowenite-veins, however, show a progressive destruction of talc (Pl. XVI, fig. 3), which is replaced by carbonate until only residual cores of talc remain, while serpentine appears in irregular veins and stringers showing the characteristic structure of bowenite already described. Finally, the bowenite itself contains, as has been said, residual flakes of talc and patches of magnesite.

The evidence appears to show that the presence of the bowenite-veins is associated with intense movement, pressure, and crushing of the rock. If we suppose the talc to be converted to bowenite by such processes under deep-seated conditions, it is evident that some magnesia is left, which presumably forms magnesite by subsequent carbonation under conditions of atmospheric weathering.

The following analyses illustrate the process of alteration, No. I being the theoretical composition of talc and Nos. II, III, and IV being analyses of the talc-rock showing progressive stages of alteration to bowenite and magnesite.

	I.	II.	III.	IV.
H_2O	4·80	5·24	5·46	6·86
SiO_2	63·50	56·15	48·41	36·41
MgO............	31·70	31·22	33·05	38·61
FeO	—	2·71	1·46	2·15
Cr_2O_3	—	0·56	0·31	0·45
CO_2	—	4·70	12·05	15·11
Totals ...	100·00	100·58	100·74	99·59

These analyses show, as regards the chief constituents, an increase in H_2O, MgO, and CO_2, and a corresponding decrease in SiO_2, which agrees with the microscopic evidence.

Origin of the bowenite.—We have seen that the bowenite and its matrix have both been subject to intense pressure, probably concentrated in those places where bowenite-veins now occur, while the analyses show the formation of magnesium carbonate at the expense of the talc. We know, further, that the change from talc to serpentine is one that can take place only under fairly deep-seated conditions of metamorphism [22, p. 351], talc being, under superficial conditions, practically an end-product. The formation of the bowenite appears therefore to be due to dynamic effects, while the magnesite has doubtless been formed subsequently, under more superficial conditions, from talc and from excess of magnesia left during the serpentinization. Further than this it is difficult to go, without more detailed field-study of the relations of the different rock-types.

Summary.—From the available evidence, it appears that the Anita Bay rocks are an ultrabasic group, probably intrusive into the surrounding rocks and differentiated during their intrusion. From analogy with the other occurrences, the talc-rock is probably a hydrated phase of the intrusion. Subsequent dynamic processes of considerable intensity account for the cataclastic structure of the dunite, and, so far as can be judged, for the formation of the bowenite.

General Remarks on the Magnesian Rocks.

(1) Original nature of the rocks.—The rocks which have here been described and discussed consist of a series ranging from diorites to dunites, and showing the greatest development near the latter end of the series. In most of the separate occurrences examined and described, the series appears to change progressively in basicity from one side to the other of the intrusion, and this seems to hold also for the prototypes of the serpentine-talc rocks.

Of the nature of the felspars little can be said, owing to their alteration (in almost every case) into saussurite. They occur, moreover, but rarely, the bulk of the rocks being peridotites. The olivine is generally near to the forsterite type. The original ferromagnesian minerals are characteristically pyroxenes, any amphiboles present being uralitic. The pyroxenes comprise enstatite, diallage, and diopside. Of these, enstatite appears characteristic of the less basic peridotites; diallage, which is the predominant species, of the intermediate types; and diopside, in subordinate quantity, of the more basic. Finally, the spinels, which are the characteristic accessories, show considerable variety, ranging from picotite in the less basic types to chromite in the olivine-rocks.

(2) Relation to the surrounding rocks.—In at least four localities the magnesian rocks are seen to be clearly intrusive into the sedimentaries, and it seems reasonable to infer that all the rocks of this series are intrusive.

(3) Correlation.—The argument for the contemporaneity of these different occurrences rests on their significant linear distribution and their remarkable petrographic similarity. It is considered almost certain that the members of the series extending from D'Urville Island in the north to Western Otago in the south were intruded, if not contemporaneously, at least during some one definite phase or period in the geological development of the island. Whether the occurrences at Milford Sound, Parapara, and Gibbston are to be grouped with the main belt, cannot be determined without further investigation, if indeed this association be ever capable of exact proof or disproof.

In short, it is highly probable that all the exposures which are included in this petrographic province were intruded during some definite stage in the process of formation of the South Island. The

structural significance of the magnesian belt (see p. 366) is too evident to be overlooked in this connexion.

(4) Age of the rocks.—Under this head little can be said, until the geological structure of the island is better understood and more fully worked out. The peridotites are intrusive into rocks which vary in age from Ordovician to Triassic or later, and it is probable that they are all of post-Triassic date. They have been, however, especially in those districts which have been most affected by mountain-forming agents, profoundly metamorphosed by regional processes. The great period of folding and of mountain-formation in New Zealand is believed to have occurred towards the end of the Jurassic or in the early Cretaceous Era, during and following the intrusion of the granitic belt along the western flank of the Alps. The magnesian rocks, therefore, appear to have been intruded during the Jurassic-Cretaceous period of folding and elevation; but their relation, in point of age, to the belt of granites which runs for some distance parallel to them, still awaits elucidation.

(5) Hydrothermal action.—The effects of contact-metamorphism have been already noticed. It remains to emphasize the hydrothermal action that has accompanied the intrusives in certain of the localities. It is noteworthy that the most highly-serpentinized occurrences are associated closely with evidences of considerable solfataric action. Thus the sulphide zone at the Dun Mountain is perfectly serpentinized, and the serpentines of the Hokitika area are likewise associated with solfataric effects. Again, where such action has been wanting, as round the dunite of Nelson and at Milford Sound, serpentinization is absent, although the rocks have often been much crushed by pressure and movement. The study of the processes of serpentinization throughout these rocks strongly suggests that hydrothermal action, during and following the intrusions, has been a potent factor of serpentinization. The uprising vapours and solutions, being entangled in the solidifying and cooling rocks, must have been active in the silicification and hydration of olivine and the consequent widespread formation of serpentine.

(6) Subsequent metamorphism.—Later alterations comprise mechanical effects on the rock-masses, and alteration of the constituent minerals. Mechanical effects due to pressure and rock-folding are seen in the shearing and foliation of serpentine- and talc-rocks, and in the cataclastic structure of some types.

As regards the alterations of minerals, deep-seated processes have effected the change of plagioclase into saussurite, of pyroxenes into uralite and into antigorite, and, apparently, of talc into bowenite. The production of antigorite and bowenite is essentially an effect of great pressure. Whether the pyroxenes change to uralite or to antigorite must obviously depend on the availability of the required

chemical constituents. Many of the antigorites, however, which were examined in the course of this work appear to be due to pressure-effects on fibrous serpentines, rather than to derivation from pyroxenes [21, p. 166].

Shallower conditions of metamorphism have doubtless been responsible for the production of bastite and of talc from pyroxene, and of some of the serpentine. A considerable amount of talc may have been produced from pyroxenes, by those hydrothermal processes which are believed to have effected or initiated much of the serpentinization of olivine.

(7) Structural significance.—The magnesian rocks which have been described constitute a belt parallel to the strike of the older sedimentaries, parallel to the granitic belt of the Alps, and parallel to the structural axis of the Alps and to the trend of the island. This combination of circumstances seems to indicate a line in the earth's crust along which dynamic forces have been concentrated. The recent volcanic zone of the Pacific, extending from the central volcanic district of the North Island, through Tofua and Savaii, to Honolulu [28], is parallel to this, although not in alignment with it; while the Tertiary volcanic rocks of the southern islands, of Dunedin, and of Banks's Peninsula also lie on another parallel line. To pursue the subject further would lead to idle speculation, and serve no useful purpose; but enough has been said to show that the magnesian belt is one of the indicators and, so far as we can judge, one of the effects of the Pacific trend-lines to which New Zealand owes its geographical position.

III. New Zealand Nephrite.

The occurrence of this mineral was first made known by George Forster [1] in 1777, and described by F. von Hochstetter [2] in 1864. Since then it has been described in more detail by MM. Duparc & Mrazec [3], Dr. Berwerth [4], and Dr. Dieseldorff [5]. In addition to this, references to and analyses of the mineral will be found in works by Fellenberg [6], Fischer [7], Damour [8], Allen [9], Arzruni [10], Clarke & Merrill [11], and others. Lastly, the recent elaborate investigations conducted by American petrologists and chemists on the Heber R. Bishop collection of jades [12] contain descriptions and analyses of New Zealand specimens. All the work hitherto done, however, has suffered from the want of knowledge concerning the mode of occurrence of the nephrite, and from the fact that none of the investigators were able to collect their material in the field.

The associations of nephrite or 'greenstone' with Maori life and lore have been carefully investigated by Mr. (now Judge) Chapman [13].

Occurrence of the nephrite.—Nephrite was known to the Maoris to exist only in the river-beaches and glacial drifts of the Teremakau and Arahura rivers and the neighbouring country. Later, when the goldfields were opened up, it was found in the drifts in considerable quantity by the miners, and it soon came into demand for jewellers' purposes. Owing, however, to the iron-stained and bleached surface of many of the boulders, there is no doubt that a considerable proportion escaped notice and were stacked during the shifting of the heavy boulders and covered over by subsequent workings. Its existence is not known in quantity in deposits south of the Kanieri district, although occasional pebbles have been picked up. It was generally understood to occur *in situ* in the ranges to the westward; but no clear idea of the locality or of its mode of occurrence was given, until the explorations of the New Zealand Geological Survey in 1906. In the Griffin Range it occurs, as already stated, in nodules and veins, varying in thickness from a few inches to a foot or more, in a mass of serpentine talc-carbonate rock. It has not yet been observed in serpentine masses, and appears to be always accompanied by talc and carbonate, notably calcite. From the ranges the tough masses, freed from their soft matrix, were transported, during the Pleistocene extension of the glaciers, by the ice which filled the river-valleys, until they found a resting-place in the glacial and fluvio-glacial drifts deposited on the coastal plain.

Hochstetter [2] and Dr. Dieseldorff [5] both record nephrite from D'Urville Island, and the latter also from Stephen's Island in Cook Strait. One of Dr. Dieseldorff's specimens was enclosed in serpentine, but no description of its occurrence *in situ* is available.

General Description of the Nephrite.

Specific gravity and hardness.—The specific gravity of the mineral varies from 2·95 to 3·05, the average density of pure specimens ranging between 3·00 and 3·04. A series of determinations made on different varieties of New Zealand nephrites showed no definite variation of density in the different types.

The same remark applies to the hardness. The hardness of translucent and opaque, of pale and dark specimens alike, stands at 6·5 (Mohs's scale), and no uniform variation can be detected. A fractured surface is softer, its hardness varying from 4·5 to 6; but the tests for hardness were made on polished surfaces crossing the grain or cleavage of the specimen. Examination of specimens split and polished parallel to the cleavage gave practically the same figure, 6·5. It appears, therefore, that the direction in which a specimen is cut has little influence on its hardness, provided that in each case a polished face be tested.

Structure.—The typical structures of the mineral, as examined in the hand-specimen, are two, namely: (*a*) slaty or fissile

structure, and (*b*) horny structure. The former type breaks with a more or less slaty cleavage; while the latter has an irregular fracture and yields little evidence of grain. Microscopic examination shows that the two types differ in the arrangement of their fibres, the slaty specimens having a schistose or foliated structure of their fibres, while the fibres in the 'horny' specimens show a confused, felted, and tufted arrangement.

Colour.—Some of the New Zealand green nephrites are the most highly-translucent specimens of this mineral that have ever been observed, with the exception of the rare 'emerald jade.' The general appearance of the mineral varies considerably, although the colour is a dark green (var. kawakawa), which may either be very clear and highly translucent, or full of small black spots and secretions, clouded and streaked, or dense and opaque. The different shades have been variously described as light green, dark green, spinach-green, seaweed-green, and olive-green. Of these, the spinach and seaweed shades are the commonest; olive-green occurs locally, in streaks or veins.

Again, the tint is often observed to become much lighter, until nearly all vestige of green has gone. The type of this variety is often of a dull or pearly-grey colour, resembling some pale Chinese or Turkestan nephrites. It is called inanga by the natives, and, being of uncommon occurrence, is highly prized by them.

Another variety, likewise much valued, is kahurangi. This is of paler green and much more translucent than the typical green kawakawa. It occurs usually in streaks and veins, running through the latter stone, giving a handsome variegated appearance to the specimen. It is of such stone that the casket presented by the Maoris to the Prince of Wales, during his visit to the Dominion, was made. Kahurangi is recorded to be the most highly valued of all the varieties of 'greenstone.' The variety, however, which is almost exclusively used by the lapidary and jeweller, is the common green kawakawa: this is the only variety that usually finds its way into museums and collectors' cabinets. Thus the specimens in the British Museum (Natural History) are all of kawakawa, as likewise appear to be all the New Zealand specimens that are described and figured in the Heber R. Bishop collection.

Varieties.—The following are the chief varieties of nephrite (greenstone) distinguished by the Maoris, on the basis of colour and texture, although the differences are for the most part accidental and do not affect the essential characters of the stone:—

(1) Kawakawa: named from its resemblance to the leaf of a shrub of the same name (*Piper excelsum*).—Green of various shades.

(2) Inanga.—Dull pearly white, varying to grey and green. Is uncommon and highly prized.

(3) Kahurangi.—Pale green and highly translucent. The most highly-prized variety.

(4) Auhunga.—A somewhat opaque variety, with the green colour of Kawakawa and the opacity of Inanga.

(5) Totoweka (Weka's blood).—A variety of Kawakawa containing stains and streaks of red iron oxide. Hence its name.

(6) Raukaraka.—Named from its resemblance in colour to the leaf (rau) of the Karaka (*Corynocarpus lævigata*). An olive-coloured streaked or cloudy variety, often with a yellowish tinge.

To the foregoing list might be added tangiwai or kokotangiwai, the bowenite of Milford Sound. The word tangiwai means 'tearwater,' and was given to this stone on account of the delicate reflections and the appearance of drops of falling water occasionally seen in polished specimens by transmitted light. The bowenite has been already described.

Mr. Chapman has applied the Radde colour-scale and nomenclature to denote the different shades [13]; but, owing to the fact that almost every conceivable variation of tint and shade may be seen, even in a single specimen, the scale is not of great practical utility.

Causes of the variations in colour and appearance.—The essential pigment of the mineral appears to be ferrous silicate. A series of analyses made by me of specimens ranging progressively in colour from the pearly Inanga to the deep-green Kawakawa showed a proportionate increase in the percentage of combined ferrous oxide (see later); there can be consequently little doubt that the essential colouring-matter is ferrous silicate. The composition, in fact, varies between that of tremolite and actinolite, although most of the specimens are actinolitic in composition. Infiltrated oxides of manganese and iron account, for the most part, for the black opaque spots, secretions, and markings which are frequently present: these, indeed, largely detract from the appearance of such specimens for jewellers' purposes.

Thickly clouded and variegated specimens, exhibiting varying shades of green, show corresponding irregularity in the percentage of ferrous oxide; the variegation is, therefore, most likely due to local secretion of this constituent in its combinations. Alternate dark and light bands in the stone are probably a result of original differences of chemical composition.

Again, streaks in the stone may accompany cracks and flaws, with the separation of iron oxide in the cracks and its infiltration into the surrounding mass, giving dark shades of colour. The red stains of the local variety, totoweka, are likewise due to infiltrated ferric oxide.

Finally, flaws and cracks impart to the surface a mottled appearance, with white or opaque splashes of colour, due to reflections from the surfaces of fracture. Thus most of these variations are due to accidental and minor causes, and do not, so far as can be seen, indicate in any case particular modes of origin.

ANALYSES OF NEW ZEALAND NEPHRITE (see p. 371).

	I. (ii, p. 146)	II. (p, 151)	III. (p. 151)	IV. (p. 151)	V. (p. 118)	VI. (p. 109)	VII. (p. 111)	VIII. (p. 106)	IX. (p. 118)	X. (p. 340)	XI. (p. 340)	XII. (p. 343)	XIII. (p. 97)	XIV. (p. 358)	XV. (p. 216)
SiO_2......	58·14	57·78	56·41	56·63	56·73	57·35	57·38	56·55	55·99	55·59	57·96	52·38	57·75	51·70	56·34
Al_2O_3 ...	0·98	2·35	0·91	2·14	3·22	0·22	0·22	0·21	—	1·43	—	2·07	0·90	0·65	1·60
Fe_2O_3 ...	3·39	1·60	3·84	3·99 ?	—	—	—	—	—	—	—	—	0·38	—	—
FeO	0·85	2·83	1·92	—	5·96	5·94	3·50	6·21	5·20	6·15	6·40	4·36	4·79	7·62	4·86
MgO ...	22·38	14·80	19·09	21·69	19·42	20·70	22·32	19·78	21·67	21·24	22·15	20·74	19·86	23·50	20·23
CaO	12·53	15·02	12·81	13·41	13·24	13·47	13·68	13·60	14·18	12·93	13·49	15·73	14·89	13·09	13·51
Na_2O ...	0·36	1·63	2·64	0·20	—	—	0·69	—	—	—	—	—	—	—	0·58
K_2O	—	1·00	—	0·69	—	—		—	—	—	—	—	—	—	
H_2O	1·69	2·75	2·56	1·67	0·83	3·13	2·78	2·81	2·56	2·35	—	2·77	0·68	2·42	3·57
MnO ...	0·22	—	0·15	—	—	—	—	—	(Cr_2O_3=0·42)	(Cu=0·17)	—	—	0·46 (NiO=0·22)	tr. (Cr_2O_3=0·30)	—
Totals ...	100·54	99·76	100·33	100·42	99·40	100·81	100·57	99·16	100·02	99·86	100·00	98·05	99·93	99·28	100·69

Chemical composition.—A number of analyses of New Zealand nephrite have been made by different workers, and the chief of these are here tabulated for reference and comparison (see Analyses I–XV, p. 370).

The following additional analyses, made by me on a series of five specimens, show the variation in percentage of ferrous oxide with variation in colour :—

	XVI. (deep green)	XVII. (medium green)	XVIII. (olive-green)	XIX. (pale green)	XX. (greenish white).
SiO_2	56·25	56·01	55·89	57·45	58·28
Al_2O_3	0·42	0·65	2·34	1·09	0·88
Fe_2O_3	1·67	1·88	2·39	0·24	0·29
FeO	5·61	5·02	2·34	1·35	0·35
MgO	20·55	20·65	18·72	20·61	22·08
CaO	12·67	13·41	13·97	15·41	14·98
Na_2O	0·35	0·45	0·51	—	0·42
K_2O	—	0·28	—	0·51	0·38
H_2O	1·89	2·03	2·21	2·65	1·98
MnO	0·33	0·29	0·41	0·28	trace
Totals	99·74	100·67	98·78	99·59	99·64

It should here be pointed out that the commonest variety of New Zealand nephrite is the green kawakawa, with an iron-oxide percentage varying from 4 to 6.

As regards the minor constituents, alkalies have not generally been estimated in former analyses of nephrites; but the recent extensive series of analyses by Walden [12, pp. 146 *et seqq.*] have demonstrated the almost universal presence of one or both of the alkalies in nephrite, and such proves to be the case in the specimens analysed by me.

Chromium is not a regular constituent. Out of eight specimens tested I found it in only one, and a slide cut from this specimen showed grains of chromite under the microscope. Chromium-compounds certainly do not constitute a pigment in the New Zealand stone. Manganese is very generally present in small quantities, as recorded also by Walden [12, *loc. cit.*] and by Dieseldorff [5]; while the latter found traces of copper in one specimen. It may here be noted that his specimens were from a locality where copper-ores have been located and prospected.

Chemical constitution.—Dr. F. Berwerth, from his analyses of New Zealand nephrite, deduced the formulæ:

$$Si_{20}Fe_2Ca_5Mg_{11}H_6O_{61},$$

$$Si_{20}Fe_2Ca_5Mg_{11}H_8O_{61},$$

and

$$Si_{20}FeCa_5Mg_{12}H_6O_{61},$$

which, he showed, approximate very closely to the percentage composition of the specimens examined. He points out that there is an excess of silicate over that present in the normal silicate of the type $R''SiO_3$ [4].

Dr. Dieseldorff, in his investigations, concluded that a satisfactory chemical formula could not be drawn up, and pointed out that mixtures or contaminations appeared to be present [5].

Dr. F. W. Clarke, in his discussion of the results of the extensive and careful analyses of the Heber R. Bishop nephrites, which include specimens from all over the world, concludes that the presence of alumina, soda, and ferric oxide are satisfactorily accounted for, on the assumption that small quantities of the glaucophane $\{Na_2Al_2(SiO_3)_4\}$ and riebeckite $\{Na_3Fe_3(SiO_3)_4\}$ molecules are present, associated with the nephrite molecule. He reduces the analyses, and calculates the percentage composition of the three constituents—nephrite, glaucophane, and riebeckite. The results, which show that this hypothesis accounts very well for all the constituents, give sufficient ground for concluding that Dr. Clarke's interpretation of the composition of nephrite is the correct one.

The results of his calculations of two analyses of New Zealand nephrites are here inserted for reference. In making the calculations, he combined the alumina and ferric oxide with enough silica and alkalies to form the glaucophane and riebeckite molecules. The remaining silica was then combined with FeO, MgO, CaO, H_2O, to form a silicate, nephrite, of the general formula $RSiO_3$ (where R = Fe, Mg, Ca, H_2). The analyses are by Walden, and the reductions by Clarke.

No. 160 [12, vol. ii, p. 146].

		Glaucophane $AlNaSi_2O_6$.	*Riebeckite* $R_2^{III}(SiO_3)_3$.	*Nephrite.*	*Abstract.*	
SiO_2	58·14	1·40	4·50	52·24	Nephrite	89·52
Al_2O_3	0·98	0·59	0·39	......	Glaucophane ...	2·35
Fe_2O_3	3·39	......	3·39	......	Riebeckite	8·28
FeO	0·85	......	......	0·85	excess H_2O ...	0·39
MnO	0·22	......	......	0·22		
MgO	22·38	......	......	22·38		100·54
CaO	12·53	......	......	12·53		
Na_2O	0·36	0·36				
H_2O	1·69	......	......	1·30		
Total ...	100·54	2·35	8·28	89·52		

No. 299 [12, vol. ii, p. 151].

		Glaucophane ($AlNaSi_2O_6$).	*Riebeckite* $R_2^{III}(SiO_3)_3$.	*Nephrite.*
SiO_2	56·41	2·14	5·76	48·51
Al_2O_3	0·91	0·91	......	......
Fe_2O_3	3·84	......	3·84	......
FeO	1·92	......	......	1·92
MnO	0·15	......	......	0·15
MgO	19·09	......	......	19·09
CaO	12·81	......	......	12·81
Na_2O	2·64	0·55	1·49	0·60
H_2O	2·56	......	......	1·15
Total ...	100·33	3·60	11·09	84·23

Abstract.	
Nephrite	84·23
Glaucophane ...	3·60
Riebeckite	11·09
excess H_2O ...	1·41
	100·33

Microscopic characters.—It is noteworthy that nearly all the minor differences in colour and structure by which hand-specimens are distinguished, disappear almost entirely when sections are examined under the microscope. The mineral aggregate is practically colourless, and non-pleochroic. The structure shows up to most advantage under high powers and between crossed nicols. It is then seen to consist of a dense mass of extremely fine amphibole-fibres, closely interlocked, and either roughly foliated, or arranged in sheaves, tufts, and radiating groups; but throughout the rock a more or less banded or foliated structure is evident, indicating considerable pressure and movement (Pl. XVI, fig. 4). The fibres are so highly twisted and felted that it becomes difficult to measure extinction-angles. When the extinction can be observed, it is very often straight; but it varies from 0° to 20°, the highest measured angle being approximately 20°. This was the angle for New Zealand nephrite observed by Dr. Clarke & Prof. Merrill [11]. Prof. Iddings obtained 15° as his highest angle [12, p. 85], while the angles for related species recorded by other authorities are as follows:—

J. D. Dana, 'System of Mineralogy' 6th ed. (1892) p. 389, 15° (actinolite).
C. Hintze, 'Handbuch der Mineralogie' vol. ii (1897) p. 1188, 16°–18° 30′ (non-aluminous hornblende).
A. M. Lévy & A. Lacroix, 'Les Minéraux des Roches' 1888, p. 144, 15°.

Of accessory minerals, epidote appears to be present in pale-yellow or colourless granules and needles of extreme fineness. Magnetite is frequently present in small grains. Chromite is only an occasional accessory, but there appears to be another spinel present in small brown grains: this is probably picotite. Lastly, small granular garnets occur, colourless to pale brown. Dr. Dieseldorff records epidote and garnet in specimens from D'Urville Island [5, pp. 340 *et seqq.*], a locality which I was unable to visit or to collect

from. Prof. Iddings, again, suspects that some small red-brown isotropic grains with an opaque border like leucoxene, in a New Zealand specimen examined by him, may be perovskite [12, p. 94, specimen 286]. Similar grains were present in most of the slides examined in the course of the work; but they showed no appearance of a leucoxene border, and they have been referred provisionally to spinels. The accessories are in all cases so small that an exact determination is difficult.

The following three special types throw light on the origin of the nephrite:—

(1) The grey fibrous amphibole (Pl. XV, fig. 5) which has been described as occurring with the serpentine of the Dun Mountain, and due to contact-action, is essentially a variety of nephrite, resulting from dehydration of and addition of lime to the serpentine, or simply from the addition of lime to the original anhydrous magnesium silicate.

(2) Certain of the nephrites show, under the microscope, grains of more or less uralitized pyroxene (Pl. XVI, fig. 5). The pyroxenes, when observed, are very pale or colourless, with a rounded outline, and an extinction-angle (when the mineral is sufficiently unaltered for measurement) of 35° to 40°. The edges of the grains are frayed out into colourless fibrous amphibole (nephrite), which mingles with the surrounding aggregate; and the main mass of the individuals is partly or wholly transformed into a patchy aggregate of fine, interlacing, tufted groups of nephrite-fibres, which extinguish roughly as a whole, thus enabling the form and boundaries of the original pyroxene crystal to be made out.

The same mode of transformation of augite into nephrite was observed and described by Dr. Dieseldorff in specimens from D'Urville Island [5, pp. 340 *et seqq.*]. I have found it only rarely in the West Coast specimens, the uralitization being generally too complete to enable the process to be followed.

(3) A specimen may here be described which illustrates still another mode of derivation of nephrite, and one, so far as I know, hitherto not observed in nephrites from any locality. The rock in question has not been recorded *in situ*, and was secured, apparently without a definite locality-label, from the New Zealand & South Seas' Exhibition held in Dunedin in 1890. It is believed to have come from the region of peridotites described by Ulrich in North-Western Otago. For specimens of it I am indebted to Prof. Marshall. It is dense and tough, fine in grain, greyish black in colour, and has a specific gravity of 3·012.

Under the microscope the rock shows the direct transformation of olivine into fibrous amphibole (Pl. XVI, fig. 6). It consists of a mosaic of rounded olivine grains, pierced in all directions by a crossing and confused network of very fine amphibole fibres. The residual

olivine cores are perfectly fresh, without any sign of serpentinization. In many places, the fibres, which are colourless and have a maximum extinction-angle of 18°, appear to be working their way towards the centre of the grains of olivine, replacing it as they grow. Finally, the olivine is more or less completely replaced, a few small residual grains being left in a dense mesh of fibres. The latter as a rule have no dominant direction, but interlace and cross one another at all angles. At other times the olivine is crossed by a series of more or less parallel cracks, which are occupied by fine amphibole fibres disposed across the cracks. The structure is altogether distinct from the serpentinization of olivine, and cannot be mistaken for it. The other constituent of the rock is pyroxene (probably enstatite) in fairly coarse irregular plates, completely converted into a dull brown bastite, with a fringe of opaque iron oxides. There is no trace of uralitization of the pyroxene, and there is little doubt that the alteration-processes observed in this rock are two: namely, serpentinization of the pyroxene, and nephritization, if one may use the term, of the olivine. The rock has, however, not undergone the shearing and stress which would be necessary to transform it into true nephrite.

An analysis of the specimen yielded the following result:—

SiO_2	43·00
Al_2O_3	2·35
Fe_2O_3	2·09
FeO	4·68
CaO	10·65
MgO	32·24
K_2O	0·24
Na_2O	0·31
H_2O	4·07
Total	99·63

The analysis thus gives evidence of exactly those changes which are observed under the microscope. They may be illustrated by the following equations:—

(1) $3Mg_2SiO_4 + 2CaO + 5SiO_2 = 2CaMg_3(SiO_3)_4$
Olivine (forsterite). Amphibole.

(2) $3MgSiO_3 + 2H_2O = H_4Mg_3Si_2O_9 + SiO_2$
Enstatite. Serpentine.

Since the serpentinization of the enstatite involves loss of silica it is possibly this silica which is added to the olivine along with lime to effect the change of olivine into amphibole. The lime has been derived, either from some other constituent of the rock, or from a neighbouring source. The change is a most peculiar one,

and the full explanation must await the discovery and study of the rock *in situ*.

Here one can only remark that the original rock was of hartzbergite or similar type, that the alteration is apparently a deep-seated one, and that the resulting aggregate of fibrous amphibole has all the characters of nephrite, except the foliated and felted structure, which is evidently due to great mechanical stress and pressure.

Origin of the Nephrite.

Arzruni divided nephrites, according to their mode of origin, into two classes:—(1) Primary nephrite, and (2) secondary nephrite, or nephrite derived by uralitization of pyroxenes [14].

Dr. Dieseldorff's examination of the nephrite of D'Urville Island showed that his specimens were due largely to uralitization of pyroxenes [5, pp. 334 *et seqq.*].

Traube's work on the nephrite of Jordansmühl [15] shows the nephrite of that locality to have been formed partly by dynamic metamorphism apparently of serpentine, partly by contact-action on the surrounding granulite, and partly by uralitization of pyroxene. The nephrite of the first mode of origin is of a pale colour, that due to the other two processes is dark green.

Again, the Reichenstein nephrite has been shown by Traube to be due to the uralitization of diopside [16] accompanied by a decrease in the percentage of lime from 21·41 per cent. in the diopside to 11·16 per cent. in the nephrite.

The recent investigations of Prof. Iddings, on the Heber R. Bishop collection of jadeite and nephrite, show how widespread is the occurrence of secondary nephrite; and he has concluded that the uralitization of pyroxenes in general, and of the fibrous species jadeite in particular, is the normal mode of origin of nephrite [12, pp. 91 *et seqq.*].

The nephrite of Southern Liguria has recently been the subject of a paper by Dr. Kalkowsky [17]. The mineral occurs in association with talc, serpentine, and calcite, the less-altered rock-types being euphotide or other saussurite-bearing rock. The nephrite is always found in the neighbourhood of faults or dislocations. He emphasizes the fact that nephrite is to be regarded as a rock or as a mineral-aggregate, rather than as a mineral, and he considers that it was here formed under deep-seated conditions by dynamic metamorphism of the serpentine-talc-carbonate rocks, assisted by movement and intense pressure [17, p. 375].

On reviewing the evidence as to the genesis of different nephrites, it appears that no one universal mode of origin for the mineral can be asserted; each occurrence must be studied on its own merits. Jadeite having been shown to be a product of metamorphism of alkaline rocks [12, p. 187], it is evident that nephrite, which nearly always occurs in association with ultrabasic rocks or their alteration-products, cannot often have been derived by uralitization of jadeite.

Turning to the nephrite of New Zealand, my conclusions are that its formation has been due to more than one type of chemical and mineralogical change. Of the four following modes of origin advanced, there is direct petrographical evidence of the first three, and a strong presumption of the fourth.

(1) Uralitization of pyroxenes.—The process, as observed microscopically, has already been described, and it is further to be noted that this general process is the commonest mode of deep-seated alteration of the pyroxenes throughout these magnesian rocks. This mode of origin of the New Zealand nephrite has been described in some detail by Dr. Dieseldorff [5, pp. 334 *et seqq.*].

(2) Contact-action.—To this agency has been due the fibrous amphibole described from the serpentine of the Dun Mountain district, adjoining the limestone-contact.

(3) Direct change of olivine into nephrite.—This change, described above, has not, so far as I am aware, been recorded hitherto; but there is no doubt that, in the specimens examined, it is seen in progress. It may be noted that, unlike the uralitization of pyroxenes, it involves a change from orthosilicate to metasilicate.

(4) Deep-seated metamorphism of serpentine-talc-carbonate rocks or of their prototypes.—The evidence for the action of this process in the formation of the New Zealand nephrite is largely indirect. It is the cause assigned by Dr. Kalkowsky for the formation of the nephrite of Liguria [17, p. 375], and it is significant that the nephrite found *in situ* in the Griffin Range (Westland) is practically confined to masses of serpentine-talc rock with calcite and dolomite. This association strongly suggests a causal connexion, and it is readily conceivable that the metamorphic processes which resulted in the development of this type of rock would give rise to the fibrous amphibole nephrite. It seems, then, very probable that this general process, which may have involved, indeed, one or more of those enumerated above, has been operative in the formation of the New Zealand nephrite.

The foregoing processes are, however, all of a chemical nature, and involve nothing more than the production of an aggregate of fine amphibole fibres. Over and above these changes, the factor essential to the production of true nephrite is the mechanical one of intense pressure and movement, superimposed on the production of the fibrous amphibole. Thus true nephrite shows under the microscope a foliated or felted structure, to which it owes its very superior hardness or toughness, and which is certainly the result of great pressure and movement. Further, the nephrite is found only in those localities where, other things being equal, the matrix shows

evidence of great pressure and shearing. Finally, the fibrous amphiboles of secondary origin, as the uralitized pyroxenes of the Cow Saddle, the altered olivine described above, and the amphibole of contact origin at the Dun Mountain, have not been transformed into true nephrite, apparently owing to the absence of the necessary dynamic stress which is essential to its formation.

In conclusion, the formation of the New Zealand nephrite is considered to have been accomplished by the formation of fibrous amphibole by one or other of the methods discussed above—followed by the action of great pressure and stress during rock-folding, on the fibrous aggregates. The mechanical factor, as well as the chemical one, has been essential to the production of the different varieties of nephrite which occur.

I wish here to express my warmest thanks to Mr. P. G. Morgan, of the New Zealand Geological Survey, and Prof. P. Marshall, of Otago University, Dunedin, for specimens of rocks given to me; and to Prof. W. W. Watts, of the Imperial College of Science & Technology, for advice and suggestions in the preparation of this paper.

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EXPLANATION OF PLATES XV & XVI.

[All the figures are magnified 20 diameters.]

Plate XV.

Fig. 1. Tourmaline-rock: Parapara. The marked cross-fracture is shown in the coarse tourmaline-crystals. (See p. 354.)

2. Dunite: Dun Mountain, Nelson. The slide shows rounded grains of olivine, with some chromite (black). (See p. 357.)

3. Garnet-pyroxene rock or garnet-gabbro: from the contact-zone, Nelson. The darker portion is lime garnet (grossularite); the lighter parts consist of diallage. (See p. 358.)

4. Epidote-rock: from the contact-zone, Nelson. The slide shows a mass of interlacing crystals and needles of epidote. The black fragments in the centre are of pyrrhotite. (See p. 358.)

5. Amphibole-serpentine rock: from the contact-zone, Nelson. Consists of veinlets of fibrous amphibole (grey) ramifying through serpentine (colourless). (See p. 359.)

6. Serpentinized dunite: Nelson. Residual cores of olivine in a mesh of serpentine, with a few grains of chromite. (See p. 357.)

Plate XVI.

Fig. 1. Bowenite: Anita Bay (Milford Sound). A very fine-grained, foliated serpentine aggregate. Polarized light. (See pp. 361–62.)

2. Bowenite matrix: Anita Bay (Milford Sound). Plates of talc appear in the centre. The remainder of the slide shows colourless foliated serpentine (bowenite), with a few small grains of chromite and some intermixed magnesite. (See p. 362.)

3. Bowenite matrix: Anita Bay (Milford Sound). The slide shows flakes of coarse foliated talc, partly altered to bowenite. (See p. 363.)

4. Nephrite: Griffin Range (Westland). The slide shows the typically foliated structure of the dense amphibole aggregate. Polarized light. (See p. 373.)

Fig. 5. Antigorite-rock: Griffin Range (Westland). The antigorite occurs as long interlacing needles penetrating the partly transformed augite, which is seen in the centre. (See p. 360.)

6. Olivine-gabbro: locality doubtful. The pyroxene is altered to bastite (black). The mottled portions consist of olivine grains undergoing a change into fibrous amphibole round their margins. (See p. 374.)

Discussion.

The Secretary read the following remarks, contributed by Prof. T. G. Bonney:—

'I very much regret that, owing to a short absence from Cambridge, I did not know that this paper would deal with the interesting rocks from the Westland district of New Zealand, or I would have arranged to stay for the night. Thanks to the kindness of Dr. Bell, I have had the opportunity of examining some of the specimens, and can see that the paper will be a very valuable addition to our knowledge of these interesting and often remarkable magnesian rocks. Had I been able to join in the debate, I should have ventured to suggest the possibility of the talc-rock and the magnesite being the result of the action of great pressure on the serpentine and the bowenite—that is, precisely the reverse of the process suggested by the Author; for, so far as my experience has gone, a talc-rock is the condition to which a much-crushed serpentine is reduced (see instances on the Gorner Grat, near Zinal, and at Plas Goch, Anglesey). Also, in regard to the nephrite, I would suggest that the direct transformation of olivine into any form of actinolite seems a difficult matter; for the former mineral contains practically no lime, the latter a considerable percentage. Must not this constituent (and some silica) be accounted for? Also I would ask, as above, in regard to the fourth mode: Is it not more likely that the serpentine-talc-carbonate rock is a further stage of change in the nephrite?

Mr. E. D. Isaacson said that it was with great pleasure that he had listened to the very able paper which they had just heard; the large amount of work put into it, both in the field and in the laboratory, was also worthy of great commendation, the former often carried out under great difficulties. As had been pointed out, these magnesian rocks were of wide distribution, and the speaker had personally been deeply interested in the metamorphism, especially the Dun-Mountain types. From his own observation, he could heartily endorse the Author's remarks, and during the course of a long residence on the Dun Mountain observed nothing to cause him (the speaker) to traverse the Author's statements.

Mr. A. R. Andrew congratulated the Author on the success of his paper, the preparation of which had clearly entailed a vast amount of labour and time, both in the laboratory and in the snow-clad fields which had been depicted on the screen. He enquired on what grounds the Author had ascribed the intrusion of these ultrabasic rocks to so late a period as the Cretaceous.

Mr. J. V. Elsden remarked upon the alteration of olivine into amphibole, which required the presence of lime. He would suggest the possibility that, in this case, the olivine might not be pure forsterite, but a lime-bearing species, perhaps of the monticellite type.

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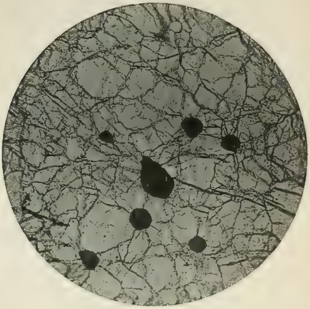

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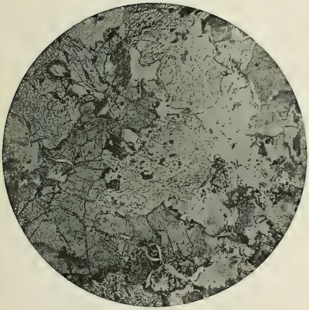

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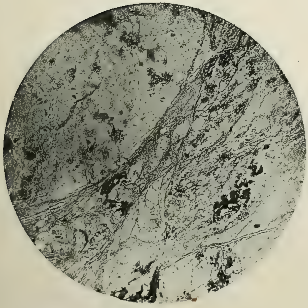

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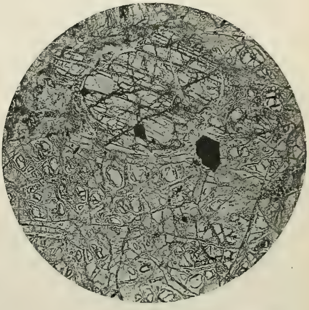
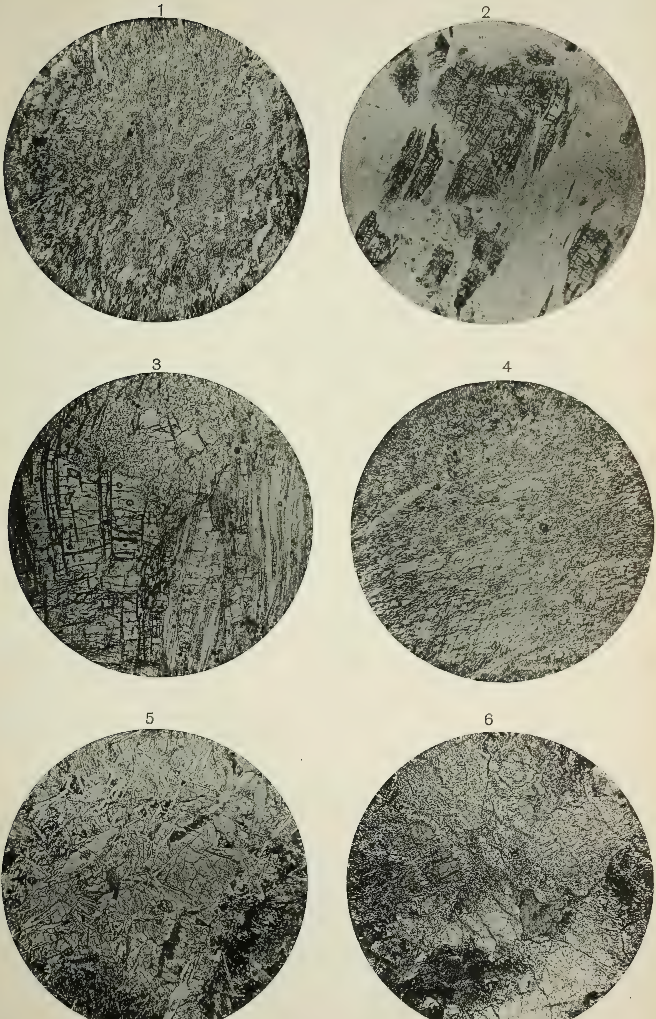


A. M. Finlayson, Photo-micro *Bemrose, Collo., Derby.*

ROCKS FROM THE SOUTH ISLAND OF NEW ZEALAND.



A. M. Finlayson, Photo-micro. *Bemrose, Collo., Derby.*

ROCKS FROM THE SOUTH ISLAND OF NEW ZEALAND.

Prof. WATTS said that it was evident that the Author had devoted much work in the field and in the laboratory to the paper, and thought that he deserved great credit for his presentation of new and difficult matter. He had not shrunk from a bold explanation of the origin of the nephrite; and it would remain for the future to demonstrate whether his inference was justified by the facts, or whether the difficulties suggested by Prof. Bonney were so considerable as to forbid the adoption of the Author's explanation.

The AUTHOR, in his reply, thanked the Fellows for their complimentary references to his paper. With regard to the points raised, the association of bowenite and of nephrite with talcose rocks seemed in this case due to a derivation of both the talc and its contained mineral from a pre-existing peridotite-mass by dynamic processes. In reply to Prof. Bonney, the Author said that the evidence showed that the bowenite and nephrite, rather than the talc-rocks, were associated with effects of rock-pressure. There was no evidence of further alteration of the nephrite by crushing, and he concluded that the nephrite was an end-product of intense pressure and movement. The source of the lime in the alteration of olivine to nephrite was an obvious difficulty, on which light would probably be thrown when the rock was studied in its field-relations. The olivine might possibly be monticellite, although the olivines of these peridotites were not, so far as he had examined them, lime-bearing varieties. In any case, the change to nephrite was here a direct alteration, there being no trace of intermediate products such as serpentine. The evidence as to the age of the intrusions was more or less arbitrary, and rested on the assumption that the period of uplift of the rocks of the Alpine range was late Mesozoic. He was indebted, for some of the specimens of nephrite exhibited, to Mr. Frank Hyams, of Bond Street, one of the pioneer collectors of the mineral.

20. *The* Lahat 'Pipe': *A* Description *of a* Tin-ore Deposit *in* Perak (Federated Malay States). By John Brooke Scrivenor, M.A., F.G.S., Geologist to the Federated Malay States Government, and formerly of H.M. Geological Survey of the United Kingdom. (Read April 7th, 1909.)

The Kinta District of Perak, chief of the four Federated Malay States (Perak, Selangor, Negri Sembilan, and Pahang), has, for many years, been famous as a producer of tin-ore. By far the greater proportion of the ore has been derived from detrital deposits; but exceptions to the rule have been afforded by certain mines where the tin-ore (cassiterite) has been won from the crystalline limestone that forms, in part at any rate, the floor of the Kinta Valley. The deposits worked were briefly mentioned in my 'Report of Progress'[1] in 1907. Since then more information has been gathered, and it is my purpose in this paper to describe the most remarkable of all the deposits that have been yet found in the Kinta Limestone. This is known in Perak as the Lahat 'Pipe.'

The only description of the limestone tin-ore deposits of Kinta known to me is by Mr. R. A. F. Penrose, Jun.[2] He remarks that the tin-ore is associated with large quantities of iron-pyrites, arsenical pyrites, smaller quantities of chalcopyrite and bornite, and some rhodochroisite (*op. cit.* p. 147).

Outside the Federated Malay States the stanniferous deposits in limestone have been cited as examples of cassiterite occurring without tourmaline. I have in my mind particularly the discussion on Mr. D. A. MacAlister's paper 'Tin & Tourmaline' read before the Geological Society in 1903.[3]

Outside the Federated Malay States, again, only one case is known of tin-ore in limestone being worked commercially. This is near the Campiglia Marittima in Tuscany, a mineral district that has lately been described at length by Prof. L. de Launay.[4] Mr. Sydney Fawns mentions small veins traversing impure limestone in Maine (U.S.A.) and containing cassiterite, fluorite, mica, quartz, and mispickel.[5]

The question of the age of the Kinta Valley Limestone need not be discussed at length here. It is invariably, so far as I am aware,

[1] 'Report of Progress' Sept. 1903–January 1907, Kuala Lumpur.

[2] 'Tin-Deposits of the Malay Peninsula, with special reference to those of the Kinta District' Journ. Geol. Chicago, vol. xi (1903) pp. 135–54.

[3] Quart. Journ. Geol. Soc. vol. lix, pp. 53 & 54.

[4] 'La Métallogénie de l'Italie & des Régions avoisinantes: (ii) Notes sur la Toscane Minière & l'Ile d'Elbe' Compte-Rendu du Xème Congrès Géologique International, 1906, pp. 555–646.

[5] 'Tin-Deposits of the World' London, 1905, p. 158.

crystalline, without any trace of fossils. Its colour is often pure white, affording good material for ornamental work. Sometimes, however, it is composed of white-and-black bands which probably preserve the bedding of pure and impure limestones. A specimen from one of the black bands examined lately proved to be composed of calcite, carbon, lepidolite in minute flakes, and tremolite. There is good reason for supposing that these white-and-black crystalline limestones are of the same age as less altered light-and-dark (carbonaceous) limestones on the other side of the peninsula, in Pahang. This makes it permissible to regard them as being equivalent to some part of the *Productus*-Beds of the Salt Range in India. The granite that has given rise to the stanniferous deposits was intruded at a much later date, probably in Jurassic, or perhaps in Cretaceous times.

In 1903, the Société des Étains de Kinta found at the bottom of a small pit where detrital ore had been worked a mass of stone *in situ*, deep indian-red in colour, oval in shape, measuring about 7 feet by 2, and carrying a considerable amount of cassiterite. The country was crystalline limestone. The stone was followed and found to continue in depth, while the mass increased in size. The work proved highly lucrative, and regular mining operations were commenced, leading to the installation of an efficient electrically-driven plant. There was no serious cessation in the operations until 1908, when the mine had reached 314 feet, and the fall in the price of tin made it advisable to call a halt in underground work, and confine expenditure to crushing accumulated stone on the surface.

At this time (that is, in June 1908) the Société presented me with a beautiful wire model of the mine, showing the limit of working and the limit of the ore-bearing stone. Two sections have been sketched from this model, which is now in the Selangor Museum, Kuala Lumpur, and are reproduced in figs. 1 & 2 (pp. 384 & 385). Neither section is drawn strictly in one vertical plane, but a comparison of the two will give some idea of the form of the deposit, and of the mass of tin-ore that has been won by following down a small outcrop.

Statistics of output, kindly supplied by M. E. Legros, are as follows:—

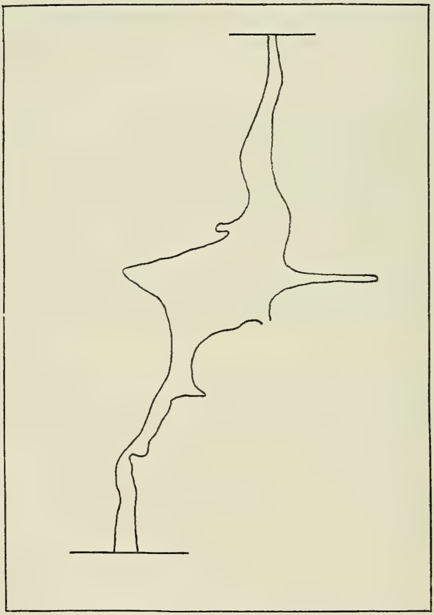
Stone crushed since operations commenced until the end of 1907	30,000 cubic yards.
Dressed ore won	20,000 pikuls.

The weight of one cubic yard of calcite (the matrix of this stone) being taken as 2 long tons, and a pikul being 133·3 lbs., this is equivalent to 1·98 per cent. by weight.[1]

[1] The percentage is really higher, since this estimate is based on the weight of a cubic yard of unbroken calcite, whereas the cubic yardage was reckoned on broken ground.

Until a depth of 120 feet had been reached in the mine, no tin-ore was discovered in the wall of the deposit. Beyond a slight iron-staining, the crystalline-limestone country presented no remarkable feature, and the division between the ore and the wall was distinct. At 120 feet, however, small veins were found running into the country-rock. One of these veins, not more than an eighth of an

Fig. 1.—*Section of the Lahat 'Pipe,' looking north-north-eastwards (depth = 300 feet).*



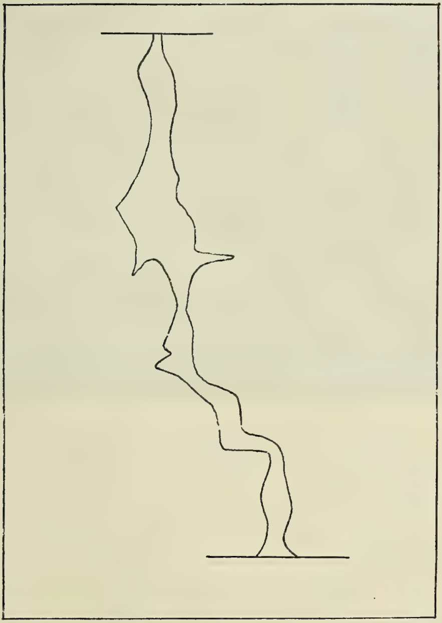
inch thick, was found to contain pyrite, a white mica, yellow tourmaline, cassiterite, and perhaps dolomite and apatite.

At about the same depth, evidence was found of a slight silicification of the limestone-wall; and with the silicified limestone were associated small quantities of tin-ore. A partly silicified specimen yielded ·083 per cent. of cassiterite.

The ore in the pipe, until work was suspended, proved to be of

the same character from top to bottom,[1] but for a few specimens which will be noticed later. Angular pieces of cassiterite could generally be seen in a hand-specimen, set in a deep-red matrix of calcite and iron-oxide. Under the microscope, thin sections showed

Fig. 2.—*Section of the Lahat 'Pipe,' looking east-south-eastwards (depth =300 feet).*

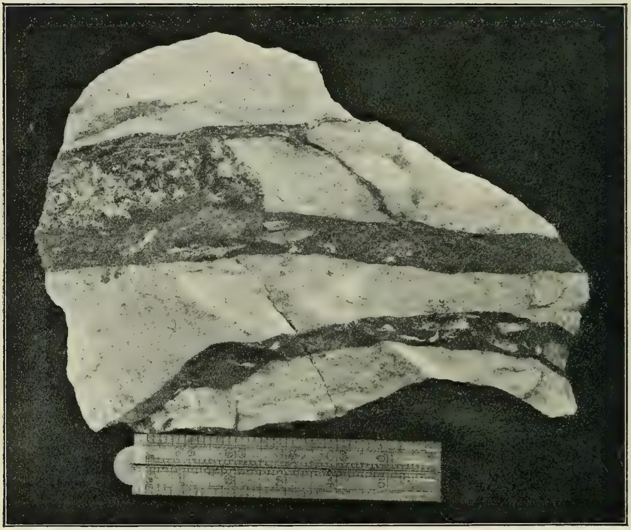


that the cassiterite was dotted about irregularly among the crystals of calcite, and that in some cases the pieces of cassiterite consisted of what appeared to be broken fragments of masses of radiating needles.

On dissolving away the calcite and iron-oxide, pieces of angular, yellowish-brown cassiterite were obtained, mostly portions of short

[1] A specimen of the ore is to be found in the Imperial Institute Collection.

Fig. 3.—*Photograph of a specimen from the Lahat 'Pipe,' preserved in the British Museum (Natural History).*



crystals, or poorly formed crystals, but in many cases small angular masses of needles. A little quartz, sometimes with distinct crystal-outline, was obtained. No tourmaline was found.

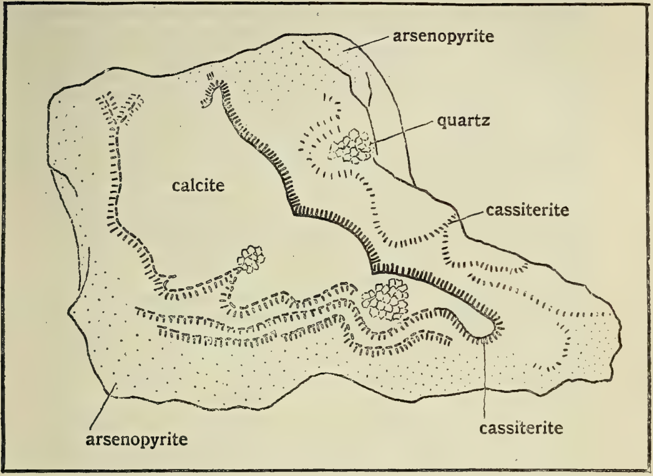
Occasionally a little pyrite or chalcopyrite was met with in the course of work, and I have been informed that it generally occurred near the periphery of the pipe.

Vughs containing calcite and chalybite-crystals were encountered.

The Origin of the 'Pipe.'

In Kinta it is easy to differentiate two distinct types of tin-ore deposits in limestone. One type yields ore that undoubtedly crystallized from vapour or solution in the place where it is now found, and we may (for convenience) refer to it as 'lode' tin-ore. The other type affords ore that has certainly been transported by water, concentrated in fissures, and then converted into solid stone by a calcite-cement derived from the walls of the fissure. The Lahat 'pipe' agrees with neither of these types; and, as no record exists of similar but smaller deposits that have been worked in past years, it must be considered as standing alone.

Fig. 4.—*Diagrammatic sketch of a specimen from the Lahat 'Pipe,' rather less than one third of the natural size.* *(See p. 388.)*



[This shows the distribution of the cassiterite, partly oxidized arsenopyrite, quartz, and calcite.]

The finest example of the second type is a deposit in a large cleft in a limestone-hill, known as Jesophat's Valley. The following points mark it as something distinct from the Lahat 'pipe':

(1) The cassiterite occurs in rounded grains.

(2) Rounded grains of quartz, tourmaline, and other minerals are abundant.

(3) No trace of silicification of the wall has been found.

A good example (also a pipe) of the first type has been worked at Ayer Dangsang, by the Société des Étains de Kinta, about half a mile distant from the Lahat 'pipe.' It shows the following points of difference:—

(1) The abundance of fresh sulphides and the absence of iron-oxides.

(2) A recognizable arrangement of the cassiterite-crystals in the calcite-matrix.

The Ayer Dangsang and the Lahat 'pipes' have points in common, however, in the rarity of quartz and tourmaline.

The question whether the Lahat pipe is a 'lode' or a detrital deposit has interested many people in this country; but, until lately, I have been unable to obtain satisfactory evidence to lead me to a definite conclusion on either side. The manner in which prisms of cassiterite and fragments of acicular growths of the same mineral were mixed up in the matrix pointed to its being a detrital deposit; but a specimen presented by the Société des Étains de Kinta to the British Museum (Natural History) in October 1905 showed that this could hardly be held to apply to the whole deposit. Fig. 3 (p. 386) is a reproduction of a photograph of this specimen. It shows distinct thin veins with included fragments of limestone, and it also exhibits a 'caunter vein'. But a microscopic examination of small fragments of the ore, which is of about the same colour as the typical pipe-ore, showed quartz-grains that might be water-worn, one or two round grains of zircon, one round grain of rutile, a quartz-grain with rutile hairs, a trace of biotite, and some yellowish-brown tourmaline.

But since I gave, in the publication referred to above, the arguments for and against a 'lode' or a cemented detrital deposit, further evidence has come to light, which leads to a very interesting conclusion. I have already recorded the occurrence of a cave at 80 feet, having its floor partly coated with ore.[1] At greater depths other caves have been found, most of which contained a thick layer of stratified iron-ochre with cassiterite and nodules of siliceous rock resembling the silicified limestone from the wall of the pipe. One cave, coated top and bottom with beautiful calcite-crystals, contained no ore or iron-ochre, but water only.

Additional specimens were obtained, too, at a greater depth of small veins in limestone like that figured; but the most illuminating specimen found was one of which a diagrammatic sketch is given in fig. 4 (p. 387). But for the fact that the arsenopyrite is partly oxidized, this could not be distinguished from specimens of ore from the Ayer-Dangsang pipe; and the evidence of this specimen and of the caves with their ore-deposits leads me to conclude that originally the Lahat 'pipe' was a deposit like the Ayer Dangsang 'pipe' and others, and that the deposit offered a convenient course for surface-waters which dissolved away the calcite-matrix and allowed the sulphides to become oxidized by the oxygen in the air accompanying the water. Caves were formed, into some of which a mass of iron-ochre and cassiterite was washed, together with nodules of silicified limestone dissolved out of the wall of the pipe. Later the flow of water ceased, and the disorganized mass of cassiterite and iron-oxides was recemented by calcite from the walls of the pipe, which still retained the same form as that which it originally possessed.

[1] 'Report of Progress' 1903-1907.

Conclusion.

To me, at any rate, it seems that a solution has been found to the puzzle presented by this most interesting tin-ore deposit. If we assume that the current of water going down the pipe was slow, we can imagine that the released cassiterite was allowed to settle down in the pipe slowly without being churned up and rounded, as was the case in Jesophat's Valley. At the same time the continuity of lines of cassiterite, such as those shown in fig. 4 (p. 387), would be broken.

The evidence obtained from the specimen now in the British Museum (Natural History) shows that some foreign material was introduced.[1]

It is safe to assume, too, that when the original calcite-matrix was dissolved, the level of the Kinta Valley was considerably higher than it is at present; and it is probable that a considerable increase in the percentage yield of cassiterite has resulted from the settling-down of material in the pipe. The miner has probably been assisted in this, while he certainly has been assisted by the natural oxidation of the sulphides.

The Lahat 'pipe' may be described in brief as a case of a 'lode' deposit being converted into a detrital deposit *in situ*.

[1] Taking into consideration the small size of the veins in this specimen, it is probable that they are not part of the original deposit, but fissures formed in the limestone by the surface-water and filled with ore from the main body of stone in the pipe. Should this suggestion be correct, the specimen could be regarded as a noteworthy example of simulation of 'lode' conditions by detrital material.

21. *Some* NOTES *on the* NEIGHBOURHOOD *of the* VICTORIA FALLS (RHODESIA). By THOMAS CODRINGTON, M.Inst.C.E., F.G.S. (Read March 10th, 1909.)

A STAY of nearly four months at Government House, Livingstone, in 1908, afforded me the opportunity of making observations at leisure and gathering the information which is embodied in the following paper.

Livingstone, now the seat of the Administration of North-Western Rhodesia, is within easy reach of the Zambesi at the boathouse $2\frac{1}{2}$ miles above the Victoria Falls. From that point all parts of the river are accessible as far as the rapids, 5 miles farther up, and downwards nearly to the Falls, which can also be reached by railway. Much time was passed on the river, and every facility was afforded me for visiting both sides of the Zambesi for some miles above and below the Falls, and for seeing the valley of the Maramba for some 6 miles upwards from its confluence with the Zambesi. I had the advantage of Mr. G. W. Lamplugh's recent papers on the Geology of the Zambesi Basin, and on the Occurrence of Stone-Implements around the Victoria Falls,[1] and also of access to maps, plans, levels, etc., prepared by the engineers of the British South Africa Company, to whom, and many others, my thanks are due for help and information.

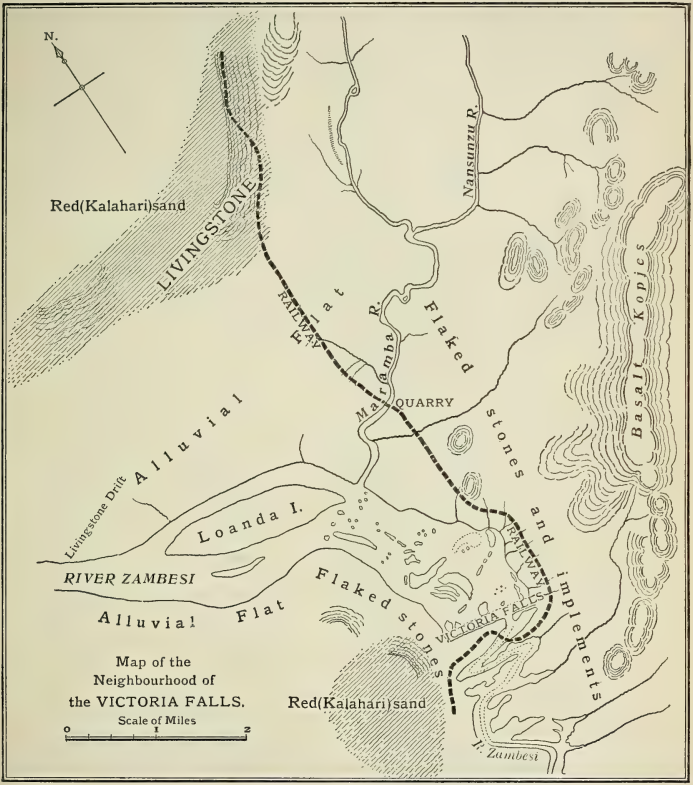
In bringing forward these observations, it is not necessary to refer to what has previously been written, as the literature has been recapitulated as lately as 1907 in Mr. Lamplugh's paper above mentioned. With what is said in that paper about the gorge below the Falls I entirely agree, and to it I have little or nothing to add.

Near the Victoria Falls the broad valley in the high plateau in which the Zambesi flows is 6 or 7 miles wide, bordered by hills of no great height, capped by sand like cayenne-pepper in colour and grain, which has been identified with the Kalahari Sand. The floor of the valley around and below the Falls is of basalt with a scanty covering of soil, and for 2 miles above the Falls basalt is seen in the islands and rocks in the rapids. It appears above the soil in places in the lower ground on the right bank, and rises 100 feet above it at and about Dales Kopje.

On the left bank basalt shows at the surface along the railway as far as the Maramba River, where an instructive section has lately been revealed. A quarry was opened where the basalt appeared as loose angular fragments of a size suitable for road-metalling, and many hundreds of tons of it have been taken to

[1] Quart. Journ. Geol. Soc. vol. lxiii (1907) p. 162, & Journ. Anthrop. Inst. vol. xxxvi (1906) p. 159.

Fig. 1.



Heights above sea-level in feet.

Low water in the Zambesi at Livingstone Drift, July 1905		2905·6
Crest of the Rainbow Fall	about	2885
Flood-level in the gorge under the Bridge		2577
Low water in the gorge under the Bridge		2521
Low water in the gorge at the edge of the map		2433
Surface of ground on the left bank of the Maramba above the railway		2935–40
Surface of ground on the east side of the gorge, 1 mile due south of the Falls		2885–86

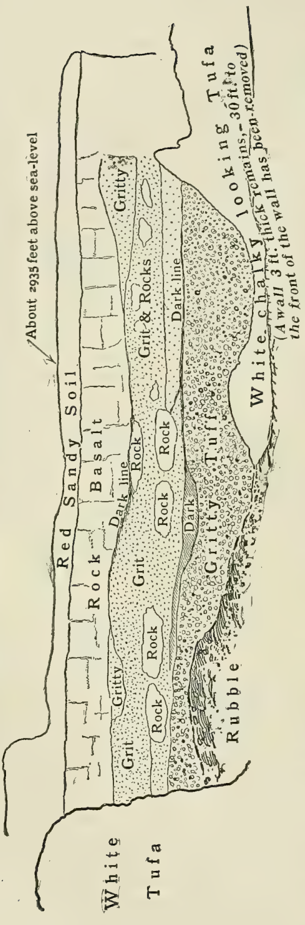


Fig. 2.—*Section in basalt-quarry, near the Maramba River.* (*Length = about 6 yards.*)

Livingstone for that purpose. Among the angular fragments are round stones from the size of a golf-ball to 18 inches in diameter. They preserve their globular form as they weather or decompose, and what looks like the segment of a bomb is often to be found; but when smaller balls were broken up they always proved to be solid. In close connexion with the loose material are beds of grit with included blocks of basalt, and a deposit of white calcareous tufa.[1] Large quantities of both have been removed, but the extent of the deposits has not been ascertained, nor has the depth been explored beyond about 8 feet. In the accompanying section (fig. 2) a bed of rock-basalt about 3 feet thick overlies a gritty bed containing blocks of basalt. The influence that such patches of loose material would have had in determining the course of the gorge is obvious.

Solid basalt appears in the bed of the Maramba near the quarry; it shows on the flat to the east of

[1] [This material, called 'tuff' in the original paper, and referred to by Mr. Lamplugh in the Discussion, proves, on examination of specimens which have reached England since, to be calcareous tufa derived from decomposed basalt. The 'grit' is disintegrated basalt. —*T. C., April 20th, 1909.*]

that river higher up; and it forms a cliff 20 feet high near the drift below the confluence of the Nansunzu. The bed of the Maramba is of basalt for several miles above this, and there are cliffs of basalt 40 feet high on the left bank, and kopjes of amygdaloidal basalt on the right bank still higher up the river. To the west of it basalt soon disappears from view, and, in a well south-west of Livingstone and about 2 miles from the Maramba, it was not reached when 20 feet of red sand and 20 or 30 feet of silt with pebbles had been passed through. No basalt is visible higher up the Zambesi than the lower end of Loanda, an island 2 miles long in the middle of the river, but it lies only a few feet beneath low water near the upper end of that island. A mile higher up, at Livingstone Drift, the river was 28 feet deep in July 1905, the bottom being 2877 feet above sea-level.[1] Rocks appear at or near low water not much higher up; and above Candahar Island, at about 7 miles above the Falls, the basalt rises above low-water level, forming rapids that extend upwards for many miles. It also rises there to a height of 100 feet on the right bank. The whole width of the Zambesi is taken up by rocks, in some places constituting weirs or overfalls for the water, in others rising a foot or two above low water in tabular masses, with deep gullies between, through which the water rushes.

Little is known of the river above this. Near Kazungula, some 40 miles higher up, where the Linyanti River joins the Zambesi, it appears from a photograph and description that there is a lagoon-like reach with alluvial banks, similar to that below Candahar Island. The river, dotted with islands, is described as majestic and calm, 458 yards wide at the narrowest, and of considerable depth, and towards the end of the wet season quite 100 yards wider and more than 20 feet deeper. There are rapids above: not far below they begin again, and the river for some 40 miles down to Candahar Island is not navigable.[2] About 3 miles above the lower end of the rapids the Sinde River from the north falls into the Zambesi, after flowing between 'small stony kopjes,' presumably of basalt. It rises in the same high ground as the Maramba, to be more particularly described, and may resemble it, but it was unfortunately out of my reach.

The character of the Zambesi near the Victoria Falls has been determined by the way in which the basalt lies. A succession of rapids, extending over many miles, and ending near Candahar Island, is succeeded by a magnificent reach of smooth water, flowing, when not in flood, at about half a mile an hour, nearly 5 miles long and a quarter to half a mile wide. The banks, rising 10 to 15 feet above low-water level, are of a grey sandy silt with

[1] Railway-datum is referred to when heights above sea-level are stated.

[2] A. St. H. Gibbons, Geogr. Journ. vol. ix (1897) p. 121, and 'Exploration & Hunting in Central Africa' p. 204; A. Bertrand, 'The Kingdom of the Barotsi' 1899, p. 186, &c.

seams of fine gravel. The islands, which are submerged by high floods, are clothed with tropical vegetation and seem to consist of alluvium like that in the banks of the river, probably on a foundation of basalt. They are sometimes capped by pure white sand, such as now comes down the rapids above. This sand, quite unlike the coarser red cayenne-pepper-like sand, is found as far up the Zambesi as the 16th degree of latitude, where Captain Bertrand pitched his camp

'on an islet covered with white sand which squeaks under foot in a curious manner.'[1]

Mr. Lamplugh noticed the same in the Batoka Gorge,

'beaches of glaring white quartz-sand, loudly "musical" when trodden on.'[2]

At a distance of 2 miles above the Falls smooth water ends, the river widens, and rocks and shoals and a succession of overfalls and rapids, with intervals of stiller water and numerous islands, lead to the great cataract a mile in width. While the fall in the surface of the water in the reach above is only a few inches per mile, through the rapids below it is about 5 feet per mile, and on nearing the Falls 16 to 18 feet per mile. The crest of the Rainbow Fall is about 2885 feet above sea-level, which is 8 feet higher than the bottom of the river at Livingstone Drift.

The Falls themselves are but the last plunge of a cataract that begins with the rapids 2 miles higher up, and the effect of the retrocession of the Falls is already felt thus far above them. While the level of the water, whether the river is low or in flood, falls with greater rapidity as it nears the Falls, the average surface of the floor of the valley near the bank remains at about the same level. Deep channels in the river-bed are already eroded; one a mile above the Falls, 36 feet deep and about 20 feet below the crest of the Falls, has been proved to exist near the left bank, and there are probably others quite as deep.

Low water under the bridge spanning the gorge below the Falls is 2521 feet above sea-level, which is 364 feet lower than the crest of the Rainbow Fall; allowing 6 feet for the fall in the water-level to the bridge would make the height of the Falls 358 feet. The observed difference between low water and flood-level in the gorge at the bridge is 56 feet, and for a mile and a half below the bridge the gradient of the surface at low water is 17 feet per mile.

Along the course thus sketched, a tranquil reach between rapids, flows a river which has an annual flood rising gradually from November or December to April or May, and falling for the succeeding six or seven months. Below the confluence of the Linyanti, some 45 miles above the Victoria Falls, where the water-level is stated to be 3210 feet above the sea, the flood is said to rise 20 feet.[3] In the reach above the Victoria Falls, according to

[1] 'The Kingdom of the Barotsi' 1899, p. 166.
[2] Quart. Journ. Geol. Soc. vol. lxiii (1907) p. 205.
[3] A. St. H. Gibbons, Geogr. Journ. vol. ix (1897) p. 121.

Mr. F. J. Clarke, the average rise at Livingstone Drift is about 13 feet, floods rising as much as 15 feet, or as little as 10 feet, having been known.

There are reasons for thinking that the character of the river and the conditions causing the annual flood in the Zambesi were similar while the gorge was being cut back by erosive action far lower down than the present Falls, and that there were, then as now, many miles of rapids above Candahar Island leading to a placid reach in which the water was held up, probably at a higher level, by rapids much longer than at present. Evidence of these conditions remains in the alluvial deposits on both sides of the river. On the right bank below the rapids a narrow terrace, 15 or 20 feet high between the river and a steep bank of basalt, widens out into a flat, thickly covered with trees and bushes, through which it is not easy to make one's way or see much. Towards Dales Kopje it becomes more open, and narrows to less than half a mile, and the basalt begins to show through the soil. On the left bank the flat is clearer of trees and bush, and is traversed by shallow dry watercourses which become flood-channels when the river is in flood. Two of these enter the Zambesi opposite Loanda Island, and another about a quarter of a mile below Candahar Island. Still nearer the rapids a lively brook, fed from the rapids, flowed into the Zambesi in May and June, but dried up as the river continued to fall. Except in the river-bank, where a few seams of fine gravel appear, no sections are to be seen. Bones and teeth of hippopotamus lay strewn on the surface, and there seems to be no reason why remains should not be found buried in the alluvium. The well sunk at Livingstone is suggestive of what may be revealed by future excavations. Under 20 feet of red sand, what is described by Mr. F. J. Clarke, who saw the well sunk, as a grey clayey silt, with stones and pebbles, was reached and was sunk into for 20 or 30 feet. The red sand is probably drift from the slope above; red sand overlying the grey silt is to be seen in several places between that and the river.[1] The top of the clayey silt seems to have been 20 or 30 feet above present Zambesi floods.

The flat extends down the Zambesi to beyond the Maramba, merging into the fluviatile deposits of that river which will be mentioned again later. Farther down the basalt rises to the surface, covered in places by gravel which will also be reverted to.

The artificially worked stones found so abundantly on both banks begin to appear on the right bank about 2 miles above the Falls, where the alluvial flat ends and the basalt, with the quartzite from which they are made, appears above the soil. Pieces of this material, described by Mr. Lamplugh as chalcedonic

[1] The red sand, where not covered by vegetation, is drifted by the wind. 'Sand-devils' are to be seen, and there is wind enough to render the river rough for boating in June and July.

quartzite, are found scattered on the surface, and sometimes forming with rolled stones and pebbles a scanty gravel. Stones artificially worked are found between the river and the high ground about Dales Kopje, and onwards to the Falls. They are perfectly sharp in the chipping, often retain portions of the rough outer crust of the quartzite, and possess little or no polish. On the high ground of Dales Kopje, rising 100 feet above the valley, no worked stones came under my notice, nor were any seen on the bank rising to about the same height opposite Candahar Island, although at both places the basalt is strewn with pieces of the quartzite.

Below the Falls worked pieces of the quartzite are abundant on the narrow tongue of land lying south of the sharp angle in the gorge in front of the Hotel, and extending eastwards for more than three-quarters of a mile to the next angle of the gorge, half a mile south of the Eastern Cataract. A sharp descent of about 80 feet beginning not far from the railway, and marking the edge of the red sand, is succeeded by a flatter slope strewn with grey sand, with small kopjes of basalt rising out of it. In a quarter of a mile the promontory narrows to 200 yards, and farther on it is not more than 60 yards wide. It is rough and much cut up by ravines; but, as seen from the other side of the gorge on the north, the general surface appears to be at the level of the old floor of the valley, rather higher than the crest of the Falls.

Pieces of quartzite, many of them artificially worked, are to be met with where the basalt rises above the grey sandy soil. The great majority are sharp and unpolished, some of the outer rough coat of the quartzite remaining on most of them. Pebbles occur with the rough angular quartzite, and the grey sand is like that in the banks of the Zambesi, and on islands above the Falls, and now being brought down through the rapids above Candahar Island. There appears to be an old flood-course of the Zambesi across the promontory, with traces of gravel. I was able, by permission of Mr. Bromwich, of the British South Africa Company's Museum, to lay on the table, at the meeting of the Geological Society at which this paper was read, a sample of this gravel preserved by him. The sand is, with some admixture, the white quartz-sand which has been already noticed, and pebbles and waterworn stones from distant sources are mingled with pieces of the local quartzite.

A similar flood-channel may be seen across the spur between the gorge and the railway east of the Hotel, and in the Rain Forest; moreover 'fluviatile débris' is said to have been met with in the railway-cutting near by.[1]

On the left bank a tributary valley joins the main valley of the Zambesi, the sides of the former merging into the latter at Livingstone, $5\frac{1}{2}$ miles above the Falls, and at about 2 miles below them. The tributary valley is thus 6 or 7 miles wide at its

[1] A. J. C. Molyneux, 'Physical History of the Victoria Falls' Geogr. Journ. vol. xxv (1905) p. 52.

mouth, and it is broad for several miles upwards. The red sand lies on the upper slopes of both valleys, and extends down to the alluvial flat bordering both the Zambesi and the Maramba. The latter river flows down the north side of the tributary valley, and enters the Zambesi 2 miles above the Falls. It rises in what are described as 'very rough stony hills,' 25 or 30 miles from its mouth, and 500 or 600 feet above it. From May till October it is almost dry to within a mile of the Zambesi: the bed of the river, 15 or 20 feet below the sides, holding pools of water connected by rapids a few inches deep. The Nansunzu, a stream of the same character, joins it about 3 miles from the Zambesi. Many sections are to be seen in the banks of the Maramba showing a coarse gravel containing quartzite from the neighbouring basaltic kopjes, fragments of basalt from cliffs bordering on the river, and sandstone and quartzite more or less waterworn, probably derived from the country near the source of the river. A coarse conglomerate of rolled stones and pebbles in sand is seen sometimes resting directly upon the basalt and covered by silty sand, but more often overlying grey or yellowish sand at 6 or 7 feet above the bed of the river, and covered by 6 or 8 feet of loamy sand and soil coloured by red sand from the slopes of the valley. The section figured by Mr. Lamplugh,[1] in which he found, in the gravel at 5 feet from the top of the bank, an implement with the chipping freshly preserved, is no longer to be recognized; but close to it I took from the base of the gravel a flake but little waterworn, of a whitish quartzite, of which there are many pieces in the gravel. It lay 7 feet above low-water level and 5 feet below the top of the bank. An extraordinary flood in January 1908,[2] the height of

[1] Journ. Anthrop. Inst. vol. xxxvi (1906) p. 164.

[2] This flood occurred on January 29th, 1908. It rose suddenly and fell quickly, being due to heavy rainfall in the hills near the sources of the river. It seems to have been exceptionally high, as native huts standing well above ordinary floods were swamped. In July and August flood-drift remained on trees and bushes along the riverside above Livingstone, 4 and 5 miles from its mouth, as much as 20 feet above the low water. An exact measurement of the height of the flood was possible where the railway crosses the river a mile and a quarter from the Zambesi by a bridge with a 100-foot opening. The flood reached the underside of the girders, which measured 18 feet 7 inches above the water-level in July, and is 2923·7 feet above sea-level. The Zambesi was then low, and its level at the mouth of the Maramba was not more than 2903 feet above sea-level. The Maramba flood must have fallen to that, so that there was a fall of 20 feet in about 2000 yards. Flood-drift remaining 7 or 8 feet above the July water-level more than half way down to the Zambesi corroborated this estimate. Other traces of the flood remained in newly exposed surfaces of the gravel-banks higher up the river, and in sharp notches 4 or 5 feet deep cut in the sandy edge of the banks by the water as it poured off the flooded valley. In the bed of the river shoals of waterworn stones 3 and 4 inches and more in diameter remained, sometimes overlain by deposits of smaller gravel and sand several feet thick, presenting sections like those in the banks.

High torrential floods are said to occur every year in the Maramba, and to be followed in a few days by heavy rainfall at Livingstone. On January 31st, 1908, two days after the flood, 2 inches of rain fell, and on February 2nd & 3rd 9 inches of rain were registered at Livingstone.

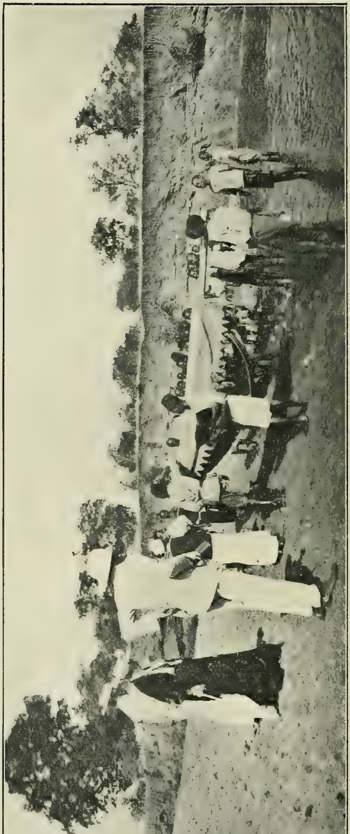


Fig. 3.—Gravel-cliff at drift, Maramba River.

which could be plainly traced by the flood-drift in the trees and bushes, rose 5 or 6 feet above the river-bank, and 10 or 11 feet above the flake. There is no doubt that both implement and flake lay at the base of a gravel of the Maramba, 3 or 4 miles from the Zambesi, and probably 30 feet above its flood-level.

I was fortunate enough to find, not far off, two implements of palæolithic type, pointed at one end, with a rounded butt. One lay on the river-bank some feet below flood-level, and the other on a shoal of stones in the dry bed of the river. They measure $6\frac{3}{4}$ inches in length and $3\frac{1}{2}$ inches in breadth; the material is a brown quartzite, and they have been much rolled. A flaked stone of the same material was also found on the bank, and other pieces were seen. Whether that material is to be met with near the sources of the river has yet to be proved.

Other specimens of worked stones of

the whitish quartzite were obtained from the bed and banks of the Maramba, and there is much of the same material in the gravel of that river. Lower down, cliffs of gravel and sand rise 20 feet above the river-bed to the floor of the valley, which slopes both towards the Maramba and towards the Zambesi; and there are, at a lower level, terraces of sandy beds used for brick-making, which seem to be more plainly fluviatile deposits of the Maramba. Flood-drift showed that the flood of January 1908 rose several feet above these terraces. On the south side of the river traces of wash and detritus, and flood-drift 4 or 5 feet above the ground in low places, were to be seen for some distance from the river as far down as the railway-bridge. The basalt appears on the surface in dry watercourses or 'spruits,' with rolled detritus, quartzite, and worked stones upon it. I picked up, among other worked stones of the usual local quartzite, a pointed shoe-shaped implement of a grey quartzite unlike the local surface-quartzite, but like other worked and unworked stones found in the bed of the Maramba higher up. It is $3\frac{1}{2}$ inches long, and quite unworn. A leaf-shaped arrow-head of local quartzite chipped on both faces, and another of the same shape having one surface flaked and the other trimmed, were also obtained on the same flat. In all, thirty-eight specimens of artificially worked quartzite were collected on this side of the Maramba above the railway-bridge, on ground 20 to 30 feet above flood-level in the Zambesi, but 4 or 5 feet below the high Maramba flood of January, 1908. The greater part of them are unworn, and none have the remarkable polish of those found nearer the Zambesi. The stones, worked or unworked, which bestrew the surface have evidently been derived to some extent from the Maramba gravel.

Below the railway-bridge the Maramba passes through a flat which may be in part a fluviatile deposit of the Zambesi, ploughed out down to the basalt by Maramba floods. At and below the bridge the bed of the river is nearly dry from May to October, when for a mile above its mouth the water is deep and nearly stagnant at the level of the Zambesi, and 16 to 20 feet below the ground at the sides. The basalt does not show above the flat, and no worked stones were seen on either side of the Maramba.

About 2 miles south-east of the Maramba and the Nansunzu a ridge of basaltic kopjes runs down the tributary valley and ends below the eastern end of the Falls. The top of the ridge, about 100 feet above the valley, is strewn with pieces of the quartzite, some of which have been artificially worked. The outer rough surface remains, the chippings are quite sharp and are weather-stained by long exposure. Some of them on the flanks of the ridge are slightly blunted at the angles, but none have any polish.

Many 'spruits,' dry except in the rains, descend from the kopjes to the Nansunzu and to the Maramba. One of the latter passes

under the railway by a 30-foot opening half a mile south of the river, which it enters half a mile lower down, and south of this the spruits flow direct to the Zambesi. For them many openings, as much as 12 to 24 feet wide, are provided to pass the storm-water under the railway, and deposits of coarse detritus and sand along their course show the violence of the streams in the rains. No less than six of them cross the path along the riverside in less than 1000 yards above the Eastern Cataract—dry, shallow, and overgrown with scrub, they are easily overlooked in the winter months (May to October), but become torrents in the rains, and in heavy storms sweep over much of the ground between them. Spruits from the southern end of the ridge enter the chasm and the gorge below the Falls, one falling into the chasm immediately below the Eastern Cataract and another into the gorge by the ravine south of the railway.

That which Col. Feilden considered to be Zambesi river-gravel,[1] near the ferry to Livingstone Island, and correctly described as containing rounded pebbles of chalcedony, quartzites, and various other rocks, with implements more or less waterworn, seems to be detritus brought down by spruits from the kopjes and valley to the eastward. It can be traced along the spruits across the railway to the higher ground beyond, and quartzites from the Maramba Valley occur in it.[2]

The implement of chalcedony described by Mr. H. Balfour[3] as having been found by him on a newly-made road on the left bank of the Zambesi, immediately above the Falls, appears to have been derived from a similar deposit. The stones laid on the road, or rather path, among which the implement was found came, it appears, not from an ancient deposit of Zambesi gravel, but from the detritus in a neighbouring spruit, either that passing under the railway by a 12-foot opening, and falling into the chasm just below the Eastern Cataract, or that rather higher up, for which a 20-foot opening is provided. It so happened that on my first visit to the place in May the path, probably near where Mr. Balfour found his implement, had lately been made good after damage done in the rains by stones from the spruit close by, and on it lay a good specimen of artificially-worked quartzite.

Mr. H. Powell, who was engaged in the construction of the railway, has been good enough to give me particulars of the finding of a perfectly-shaped arrow-head about half a mile to the east of the Eastern Cataract. He describes it as being like and about two-thirds of the size of fig. 4 (pl. xv) of Mr. Lamplugh's paper.[4] It was found in sinking a pit, under 10 feet of red sand, on the surface of basalt which crops out from beneath the sand not far

[1] 'Nature' vol. lxxiii (1905) p. 77.

[2] Judging from the present general character of the river, a deposit of Zambesi gravel here seems to be in itself unlikely; alongside rapids, and just below 5 miles of comparatively still water.

[3] Journ. Anthrop. Inst. vol. xxxvi (1906) p. 170.

[4] *Ibid.* p. 168.

off, at about 50 feet above the top of the Falls. At this level worked stones are to be found on the surface; and Mr. Powell, having experience of drifting sand in the Cape Peninsula, considers that the sand by which the implement was covered is drift-sand. The implement was sent to St. George's School, Bulawayo.

On the southern side of the ridge of kopjes running down the tributary valley are other spruits which unite and fall into the deep Zambesi gorge, at a large and intricate group of ravines a mile and three-quarters below the Falls. Very little is known of the valley on the south-east of the ridge, and the difficulty of the ground, covered by bush and trees, prevented me from learning much about it: from the ridge it appears to be more than a mile wide. The contrast between the dimensions of the ravines by which the valley drains into the gorge and those of the ravine just above seems to be too great to be accounted for solely by difference in age due to the recession of the Falls, and suggests the action of heavy floods from the valley on the south of the ridge.

On the ground round the end of the ridge are many worked pieces of the local quartzite, and with them I found an implement of the brown quartzite, in material and form exactly like the two from the Maramba River already described, but rather larger and more waterworn. It was unfortunately left behind, perhaps to be found by some future collector.

Below the Falls the ground east of the gorge, away from the ravines, is generally flat, at a level rather higher than that of the river above the Falls. The basalt is close to the surface, and the detritus scattered over it is more like a scanty gravel of the Zambesi than any seen above the Falls. It seems, however, to contain materials from the valley on the east, and this is more noticeable near the spruits draining to the gorge. There is no difference in the character of the worked stones, unless, perhaps, there be a larger proportion that retain their sharpness and are not polished.

In collecting the artificially worked stones my intention was to get a fair representative sample from each locality, but selection came about involuntarily. The flaked stones lie on the surface with many others of the same material showing no traces of flaking. The better specimens attracted notice and were picked up, while others, on which artificial working was not so obvious, were left on the ground. This was particularly the case with those picked up by the attendant 'boys.' The large proportion of flakes, and particularly of flaked stones, is not therefore fully represented in the specimens collected. It appears plain that of the many artificially-worked stones strewn on the ground very few can properly be called 'implements'; and an attempt has been made to establish a numerical proportion of those having any claim to be so considered. The specimens collected, numbering 235, not including those from the gravel and bed of the Maramba, have been sorted into flakes, flaked stones, parts of implements, and implements. 'Flakes' are

those of which one face has been struck off by one blow, and the other side is rough, or made up of two or more facets resulting from previous flaking, but without any secondary chipping of the edges. ‘Flaked stones’ bear plain evidence of artificial work, but are without any evidence of design. ‘Parts of implements’ are those in which there is enough evidence of design to justify the supposition that they are implements broken in the making, or unsuccessful attempts at working a cross-grained stone. ‘Implements’ include all recognized forms, however rough, in which the material may have been artificially shaped for use.

It is, of course, sometimes hard to say to which class a specimen should belong. Some flakes, as defined above, may be considered to be scrapers, or arrow-heads, and if so should be ranged in the class of implements; but the number of flakes left on the ground would more than make up the proportion thus lost. It is also often difficult to decide whether a specimen should be classed as a flaked stone, or as an imperfect implement. Several sortings, in which individual specimens were classed differently, have yielded much the same result on the whole, and the figures now given fairly represent the character of the specimens collected.

Of 235 specimens only 88, or rather more than one-third, show enough evidence of design to be classed as implements or parts of implements as defined above, and in the specimens from near the left bank of the Zambesi, whence more than half come, the proportion is very slightly higher. The proportion of ‘implements’ to ‘parts of implements’ is as 1 to 2. Among the former are one perfect shoe-shaped implement, two arrow-heads, stones with a cutting-edge on one side or trimmed all round, trimmed flakes, and scrapers, or sling-stones. Among the latter can be recognized the points and butt-ends of pointed implements and parts of a trimmed cutting-edge, and others are included that look more like ‘wasters’ or abandoned attempts to work a cross-grained stone. The rarity of finished implements, however rough, and the abundance of flakes and flaked stones point to the conclusion that the number of implements made was large, and that what remains is the refuse-material, the implements having been taken away for use elsewhere. The material described by Mr. Lamplugh as chalcedonic quartzite occurs scattered over the surface in rough irregular lumps with many rough cavities. Although not a good material for the purpose, it must have supplied the material for implements for a wide stretch of country on either side of the Zambesi covered by the red sand, in and upon which no stone is found. This would account for the crudeness and imperfection in the implements now found, which have been observed and commented on. There are, however, exceptions. The implement found by Mr. Balfour, the shoe-shaped implement of grey quartzite, and the arrow-heads found by myself and Mr. Powell, show that well-shaped implements were produced, and the chipping on some of the ‘wasters’ left on the ground shows considerable skill in the working of an intractable material.

It will be seen that worked stones are found on the floor of the old Zambesi Valley above the Falls, not many feet above the level of the annual flood; and below the Falls, on both sides of the gorge in which the river flows, 400 feet below; further, that in the tributary valley they are found embedded in the gravel of the Maramba, in the dry bed and on the banks of that river, and on the floor of the valley, and also on the ridge rising in the middle of the tributary valley to a height of more than 100 feet.

When the specimens from these localities are compared, the difference between them becomes apparent. Those from the ridge, retaining the rough coating, with the angles sharp and the flaked surface weather-stained by long exposure, appear to be the refuse left by fabricators of implements who were dealing with an intractable material where there were no watercourses or sand by which the waste material left behind could be rolled or polished.

Many of the worked stones from the right bank of the Zambesi have much the same character. Of the 10 specimens collected on that side above the Falls, where the spruits are few and short, the majority retain portions of the rough outer crust of the quartzite, and all are sharp and unworn, with little or no surface-polish, the majority having none. On the tongue of land below the Falls to the south of the Hotel, out of 44 specimens collected and examined 35 retain their sharp angles, part of the rough outer crust remaining on many of them, while others are polished more or less.

The large proportion of sharp unworn specimens on the right bank of the river is noticeable, especially on the tongue of land below the Falls. From their position on this long narrow promontory the artificially-worked stones must either belong to the gravel of the Zambesi when flowing upwards of 400 feet higher than at present, or must have been fashioned from quartzite-fragments found on the surface at some time since the gorge was cut out. The condition of the flaking is all in favour of the latter alternative.

Passing to the other side of the Zambesi, on the flat south of the Maramba and draining to it, the majority of worked stones retain their sharpness, but in a smaller proportion. Of 38 specimens, 22 are unworn and sharp and 16 waterworn, but none are polished.

On that part of the left bank which drains directly to the Zambesi, comprising ground between 3 and 4 miles long above and below the Falls, 130 artificially-worked stones were collected, all, with one exception, of the local quartzite. Of these, 59 are sharp in the angles of the chipping, some retaining the rough outer coat of the stone, and 71 are more or less waterworn and polished. The polish of some is remarkable, others are less polished, and some not polished at all. In one or two specimens the angles of the chipping have been blunted after the polishing. The proportion of worn to sharp specimens is here reversed. While on the right bank 80 per cent. retain their sharpness, on this part of the left

bank to which detritus is brought down from the tributary valley that is the case with only 45 per cent., those worn and polished outnumbering those retaining their sharpness by one-fourth.

The explanation seems to be that, whether on the right bank or on the left, specimens that retain their sharpness are implements, fragments, and flakes made on the spot, and that those worn and blunted have been brought down with other detritus by spruits in the rains. On the right bank spruits are short and insignificant above the Falls, and almost absent on the promontory below; while on the left bank, though many implements were made on the ground above and below the Falls, most of the artificially-worked stones were brought down by the flooded spruits from the tributary valley.

With respect to the origin of the burnish, so conspicuous on many of the stones as they lie on the surface under the brilliant African sun, it is to be noticed that there is a considerable difference in the amount of the polish on specimens from the different areas. On those from the top of the ridge there is none, nor is there any on those from the Maramba Valley; those from the right bank above the Falls have little or none, while those from the tongue of land below the Falls generally have some, and a few a good deal of polish. Of the 130 specimens from that part of the left bank draining direct to the Zambesi, not more than six are without some polish, and many are highly polished. A view of the whole of the specimens collected shows that abrasion and polish or burnish go together, those with sharp angles having little or no polish, while those that are highly polished are much worn. As far as it goes, the evidence seems to be in favour of sand-polish rather than glazing by a film on the surface.

With regard to the age of the implements, that found by Mr. Balfour and four found by me are of palæolithic type, the first and one of the latter being unworn and sharp, while the three of a brown quartzite, which seems to come from the Upper Maramba,[1] are much rolled. None of them were found embedded in a gravel or other deposit.

The implement found by Mr. Lamplugh in Maramba gravel 3 or 4 miles from the Zambesi has its chipping freshly preserved, and the flake found by me at the base of the same gravel close by is unworn. The gravel, resting directly upon the basalt 7 or 8 feet above the bed of the Maramba, may be of considerable age; though, on the other hand, it is far below the level of present Maramba floods and may be comparatively recent. Nor can any conclusion be drawn from the finding of the implement beneath 10 feet of drifted sand.

[1] The three of brown quartzite are very like implements from India in the Cape Town Museum, labelled as 'greatly resembling South African implements in material and workmanship.'

The sharpness of the angles of many of the worked stones gives the impression that the chipping can be of no great age, and there is good reason for believing that the use of stone tools has gone on in this part of Africa, as farther south, down to quite recent times. But it is remarkable that, while a few stones polished after being artificially worked have had the angles of the chipping worn rough and blunt, none of the specimens that came under my notice showed a polished surface chipped away by undoubted artificial working.

Some of the artificially-worked specimens of the local quartzite are associated with gravel belonging to the Maramba River and to spruits coming down the same tributary valley; others appear to have been fashioned from rough unrolled quartzite locally derived, and some from stones which may have belonged to the scanty gravel of the Zambesi: this, however, is no evidence of antiquity, as they may have been fashioned from stones lying on the surface at any time down to the present. The supposition that implements, or artificially-worked stones, have been found embedded in a deposit which can be considered a gravel of the Zambesi within the area that came under my notice appears baseless: nor is there any ground for supposing that those found on both sides of the gorge on the rocky surface of the old Zambesi Valley, 400 feet above the present level of the river, were there when the Zambesi was flowing at that level before the gorge was eroded. The presumption seems to be that the implements were fashioned from unworked stones found then, as now, on the floor of the old valley since the gorge was carved out.

The clue to the age of the implements will probably be found in the Maramba Valley, when the gravel and the deposits now being dug for brick-making are properly studied. It could be seen from the photographs exhibited at the meeting that tropical Rhodesia can show river-deposits that would not discredit an English river.

Discussion.

Mr. G. W. Lamplugh complimented the Author on the good use that he had made of his opportunities in the Zambesi Valley. The distribution of the stone implements on the borders of the gorge below the Falls appeared to the speaker to indicate that in some cases they had been transported by the Zambesi when it flowed at plateau-level; but the geological evidence for their high antiquity was, after all, suggestive rather than conclusive.

Until proof of the detrital volcanic character of the white rock described by the Author was forthcoming, the application to it of the term 'tuff' was hardly justified. The description of the flood in the Maramba was interesting, as showing how the bed of a main river may be channelled by a tributary—the reverse of 'hanging-valley' conditions, when, as in this case, the floods of the streams occur at the low-water stage of the river.

Mr. H. Balfour said that he approached the subject of the Zambesi stone implements chiefly from an archæological standpoint. He recognized the following points, which seemed to him to indicate clearly the high antiquity of, at any rate, a considerable number of them:—(1) Their constant association with what appeared to be ancient drift-deposits, and their relative great scarcity away from surface or bedded drifts; (2) the heavy patination so frequently seen upon the implements of chalcedony, etc.; (3) the evidence of long-continued abrasion, which seemed to show that they had in many instances been rolled along the bottom of the river for a considerable distance and during a prolonged period; (4) the fact that the forms of the larger implements more especially corresponded exactly with the characteristic 'river-drift' Palæolithic implements of Western Europe, and the absence of implements which *must* be regarded as of later type; (5) the absence of correspondence between these implements and the known forms of stone tools used by the recent native inhabitants of South Africa; and (6) their *gisement*, and particularly the fact that not only did the implements usually appear to belong to the gravel-deposits, of which they formed an integral part, but that he (the speaker) had excavated a number of them from the lower layers of undisturbed stratified gravel-beds, which were, as he believed, terrace-gravels of the Zambesi deposited by the river at a very remote period. He recognized that a certain number of the implements that were to be found in the district might be of quite recent date, but these did not affect the question of the antiquity of the remainder.

Col. H. W. Feilden remarked that, as far back as 1905, he had published his views on the river-gravels of the Zambesi Valley, above and below the Victoria Falls. In that paper he had ventured to advance the opinion that the high-level gravels, bordering the ancient river-course below the Falls, had been deposited by the Zambesi, when that river ran at the same level as it now does above the Falls, and that many of the stone implements associated with these high-level gravels were deposited at the same time. He still adhered to those views. He did not think that the Author had brought forward sufficient evidence to controvert his views, and the Author's statement that they were baseless appeared to him somewhat premature.

The President (Prof. Sollas) remarked that there could be no doubt as to the forms of the implements, which were not only Palæolithic, but Lower Palæolithic; on this point all observers were in agreement. They were also contemporaneous with the high Zambesi gravels, as was shown by the diggings of Mr. Henry Balfour and the observations of Col. Feilden; but this fact by itself was insufficient to determine their relative age. There was room for a difference of opinion as regarded the powers of the Bushmen: they were distinguished for their courage and mental activity, and the possession of the bow and poisoned arrows would have given them a great advantage over a Lower Palæolithic race. But that, as a matter of fact, they

were not the exterminators of the earlier inhabitants seemed to be shown by their own traditions, from which one learnt that they never encountered on their migration southwards any other human inhabitants. Lower Palæolithic man was extinct before the Bushmen reached the Zambesi, perhaps as the result of epidemics or the same mysterious causes as had led to the extinction of the horse in America before its re-introduction by modern Europeans. The Bushmen were probably the recent representatives of Solutréan man, and thus of Upper Palæolithic origin; but, if an Upper Palæolithic European stage was now represented in South Africa by a recent race, then a Lower Palæolithic European stage might be similarly represented by a chronologically Upper Palæolithic race. It seemed probable, therefore, that the implements exhibited belonged to a Lower Palæolithic race which inhabited the Zambesi in Upper Palæolithic times; but this, according to the argument employed, was the latest date that could be assigned to them, since the next succeeding stage was represented by recent races which were homotaxial with the Upper Palæolithic.

The Author hoped that the proof asked for by Mr. Lamplugh of the volcanic character of what he had called 'tuff' would shortly be forthcoming on the arrival of samples of the material. The reasons for a contrary opinion to that expressed by Col. Feilden, that the detritus on the left bank above the Falls was Zambesi gravel, were stated in the paper, and there the question must rest, until further evidence became available.

22. *On the* Karroo System *in* Northern Rhodesia, *and its* Relation *to the* General Geology. By Arthur John Charles Molyneux, F.G.S. (Read February 24th, 1909.)

[Plates XVII–XXIII.]

Contents.

I. Introduction.

In 1903 (in vol. lix of this Journal) I described the occurrence in Southern Rhodesia of deposits of Permo-Carboniferous age that have since been correlated with the Karroo System of South Africa. In the present communication will be traced their extension into Northern Rhodesia. There they are found occupying the lowlands of the Zambesi basin, and they also constitute the floors of the trench-like valleys of the Lusenfwa River (or Luano plains), of the Lukasashi River, and probably of the Luangwa. These depressions form a more or less continuous succession of troughs bisecting Rhodesia diagonally, along a distance of some 800 miles, that is, from the Deka River to the head of the Luangwa. They lie some 2000 feet below the surrounding country, which is of plateau type and is made up of metamorphic and crystalline rocks of the pre-Karroo complex. The change from upland to valley-plains is generally abrupt, giving rise to steep escarpments that appear as mountains when viewed from the lower position.

Nowhere, so far, in the vicinity of these depressions have 'high-level' areas of Karroo rocks been met with on the plateau, and one's first impression is that these basins are vestiges of an original landscape, in which the sediments were deposited. But we have been prepared by Mr. G. W. Lamplugh, in his description of the Deka Fault,[1] for great displacements of Karroo strata and earth-movements, and there is ample evidence to show that these valleys and low-lying regions of sediments are largely due to important folding which took place in post-Karroo times.

Apart from its tectonic aspect, the question of original difference affects the economics of the coal-distribution of Rhodesia. If these

[1] 'Geology of the Zambezi Basin around the Batoka Gorge (Rhodesia)' Quart. Journ. Geol. Soc. vol. lxiii (1907) p. 162.

valleys are but faulted-down areas, one might expect to find unfaulted remnants on the uplands. If the reverse be the case, and the coal-measures occur in pre-Karroo valleys as parts of an ancient landscape, search for coal-deposits may be confined to these, or to other valleys of corresponding features.

Geographically also, the demarcation of deposits so far north that are undoubtedly correlated with the Karroo System of South Africa is of deep interest, for, together with regions in East Africa, they form the link with the Indian provinces of Suess's ancient continent of Gondwanaland—as the Permo-Carboniferous age of the fossils (many belong to the *Glossopteris* Flora) conclusively shows.

It will be seen, then, that an investigation into the distribution of the Karroo strata in trans-Zambesia will involve us in their relationship to surface-features, and require more than passing reference to the folding movements that have influenced so much the geology and topography of these regions.

II. Physical Features.

As this paper deals with the relationship of the Karroo strata to the structure, it becomes necessary to describe some of the features of the country. At the outset, however, as I have not visited the Luangwa Valley, and it has so much in common with the parts included in my travels, I must, in introducing my subject, abstract the references of Mr. L. A. Wallace [1] to that locality.

The Luangwa Valley.

The Luangwa River rises near Fort Hill, some 40 miles west of the northern end of Lake Nyasa, and runs for a distance of 400 miles in a nearly straight line south-westwards to join the Lukasashi, between high mountain-walls that are really but the incised edges of the plateau. Near its source is the Nyika plateau of 6000 to 7000 feet, where the succession of Archæan rocks, the Mount-Waller Sandstones, and 'Drummond's beds' has been dealt with by Mr. J. E. S. Moore.[2] The left rampart of the Luangwa is the Nyasa plateau of 4000 feet — the western, known as the Machinga,[3] here reaching 5000 feet, being thus higher than its opposite wall. It is notable that Mr. Wallace states that the parts of the valley nearest the source are much more precipitous than those bordering the Lower Luangwa, although the western escarpments are again steeper than the Nyasa side.

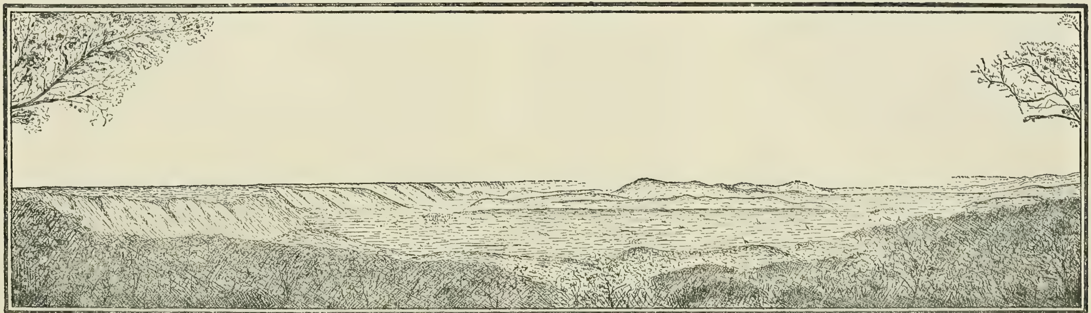
The valley, from 20 to 35 miles in width, has a flat appearance, with alluvial deposits, and a floor of sandstones and limestones of

[1] 'North-Eastern Rhodesia' Geogr. Journ. vol. xxix (1907) p. 369.

[2] 'The Tanganyika Problem' London, 1903.

[3] The native meaning of this word is 'fence.'

Fig. 1.—*The Luano Valley seen from the Matakula Pass ; looking east-north-eastwards.*



From a photograph by the author.]

probably Karroo age. In the vicinity of the Lusenfwa junction, hills of gneiss close in on the river; but afterwards the walls recede at greater slopes, and the work of subaërial denudation is much more marked. Down to this bend the direction of the valley has been parallel with the strike of the schists.

The Lukasashi Valley.

This is another notable feature: the Lukasashi River running parallel with the Luangwa and the strike of the schists, and in a similar trench-valley at the back of the Machinga escarpment. It rises near Serenje on the plateau, but for the lower 90 miles its valley has a floor of Karroo beds. On nearing the junction with the Lusenfwa, it bends and cuts across the cleavage of the schists. Notes and sections on this locality, for which I am indebted to Mr. J. M. Moubray, show that the valley below this bend intersects four small transverse valleys of sediments, divided by Archæan ridges, and apparently resembling the synclinal folds of Karroo strata (with axes corresponding to the strike of the Archæan rocks) which occur in the Luano Valley (p. 413).

All the following localities will be described from my own observations, and I have, in them, been fortunate in having had the opportunity for more detailed study of their physical conditions than is generally the case when traversing wide areas: in this way I have gathered facts which are of more than merely local value, and bear significantly on the history of all these troughs and escarpments and their associated physiography.

The Luano Valley.

This is a wedge-shaped depression, the base of which lies upon the Lukasashi, while the apex rests 28 miles away from the railway from Victoria Falls to Broken Hill (see fig. 2, p. 412). Its length is upwards of 80 miles, and the width reaches 25 miles. The walls are represented by the plateau-ramparts, which thus draw together on the west.

The northern wall, here also known as the Machinga, is wonderful for its uniform sky-line, and emphasizes the flatness of the northern Rhodesian plateau, as shown in fig. 1 (p. 410). It maintains a general direction to the east-north-east, and is lost in the haze of the distance. The échelon of bluffs shows it to be cut back in ravines where the smaller mountain-torrents are at work, and incised by deep gorges where important rivers have eroded courses from mature plateau-level to the plain. These rivers unite with the Lusenfwa as the main channel of drainage. The term Luano is regional for this low area, and is derived from the Aluano people who inhabit it. The escarpment is formed of gneiss and schist which dip southwards, and in this closely correspond with the angle of slope of the foothills. In consequence, subaërial erosion is vigorous, and vast blocks of rock constantly fall away, scouring

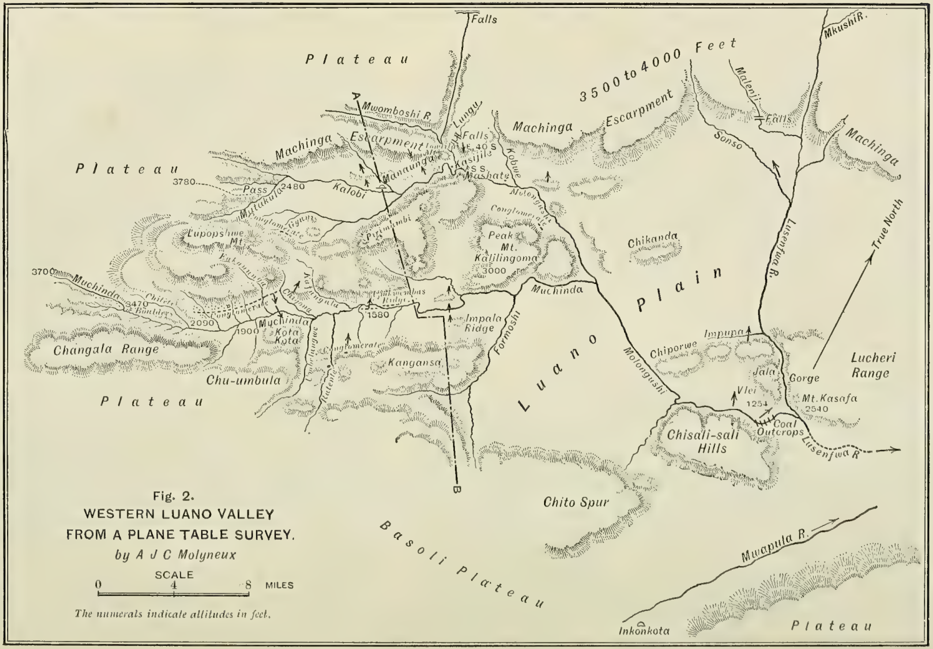


Fig. 2.
WESTERN LUANO VALLEY
FROM A PLANE TABLE SURVEY.
by A J C Molyneux

[A–B is the line of section shown in fig. 4, p. 417.]

a red pathway through the green verdure of the slopes until they come to rest, broken into fragments, on the foothills. After the opening rains of the wet season rock-slides are numerous, and remain as noticeable landmarks from a great distance.

The southern wall of the Luano plain presents a great contrast with that just described. While the Machinga keeps to the one line, and, as will be shown later, is due to a far-extending fault that brings the Karroo beds into contact with the complex, the enclosing mountains on the south side are much worn and bear evidence of submission to prolonged erosion. The main Luano is joined by a number of tributary valleys such as the Formoshi, Mwapula, etc., that run back in broad tongues with Karroo floors, divided one from the other by spurs or promontories reaching out from the plateau-level, and dying away into and under the Karroo plain. Further, the slopes on this side are less steep: they follow no set type as the Machinga does, but roll back in waves, foothills, and creeks, before the uplands are reached, 2 or 3 miles away.

The apex of the Luano wedge is bifurcated, as it were, by the Lupoposhwe promontory. On its north is the Kalobi Valley (which is also penetrated by a minor promontory, or narrow sloping hog's-back, known as the Matakula Pass) lying along the foot of the Machinga escarpment, while on the south is the beautiful Muchinda Valley. The promontory is the dome of an eastward-pitching anticline of Archæan rocks, which has been covered by Karroo beds, since removed; while the Muchinda Valley is a syncline rolled out towards the west, containing sediments of Karroo age. It is probable that the other valleys along the southern side of the Luano are of the same structure, gradually rising up to nearly plateau-level, as the folds died out westwards. The evidence regarding the Muchinda will be dealt with later (p. 431); it may be here said that masses of the basal conglomerate of the Karroo System occur high up the mountain-limbs on either side, while vestigial pebbles of the same beds exist nearly at the head of the valley.

Archæan inliers of considerable area arise from the clastic floors. Although the Lupoposhwe range dies down into the flat, it continues as an anticlinal dome of gneiss in the centre of the Luano Valley, with Karroo beds on each side, and connects with Kalilingoma Mountain. This is an inlier of Archæan rocks, covering an area of 25 square miles, and rising to about 3000 feet; that is, not quite to plateau-level. It is much incised, and is completely surrounded by the later sediments, which are tilted round it. Another inlier is Kasafa, connecting with the Lucheri range, forming a chain of metamorphic rocks parallel with the axis of the valley, and extending for some 15 miles. Its summit rises to 1286 feet above the valley, or 2540 feet above sea-level—but still considerably less than the valley-walls, from which both Kasafa and Kalilingoma are easily overlooked.

Kasafa also rises from a sea of Karroo sediments. It is opposite the gorge of the Lusenfwa from the northern scarp, which river,

meandering across the Karroo plain, passes completely through a shoulder of the inlier by a deep cleft—evidence that the course of the river was laid out at the time when the Luano was filled by a mass of superimposed strata, which has since been removed by erosion.

From another inlier, Chisalisali, Kasafa is separated by a narrow channel of sediments, in which the Molongushi is cutting down. These show a remarkable succession of the strata, in which an ascending sequence, dipping 12° to 17° northwards, of basal conglomerates, nodular ironstones, coal-measures, and fine sandy beds and clays can be measured. (See Pl. XXI.)

Other 'saddles' or domes will be noted, showing the dip of the limbs in anticlines.

If the Karroo valleys, spread out like fingers along the southern fringe of the Luano, suggest a series of folds, the running brooks that enter the valley through the great Machinga escarpment tell of other movements. Here the contact of sediments and complex follows the foot of the range in a straight line; no Karroo beds form the floors of the transverse tributary gorges on this side. Each river debouches by a cañon with precipitous sides, cut down into the metamorphic rocks, and headed by high waterfalls where the stream leaves its placid and mature course on the plateau for its rejuvenated form. Thus along the line of the escarpment, in addition to evidence that it was caused by post-Karroo faulting, we read the message of a comparatively recent change of level in the Karroo surface, by which the plateau-rivers were required to fall over an emerging escarpment of Archæan rocks. It will be shown later (p. 436) that this rejuvenescence and change of level is due to the more rapid erosion of the sediments that probably filled the Luano to plateau-level, and to the removal of some 2000 feet of strata.

In describing the northern affluents of the Luano, they will be taken in succession from east to west. As this valley is drained eastwards, the theory of erosion would presuppose that the western portion is newer and more lately removed than in the former direction.

The Lusenfwa River.—The early course of this river, the only perennial one of the district, undulates across the even surface of the plateau of 4000 feet, and little below its watershed contours. From Boé's Ferry rapids commence, and 3 miles farther down its high-level course comes to an end (3045 feet above sea-level) by waterfalls of 250 feet, which head a cañon of some 15 miles, cut back into the plateau from the Machinga escarpment.

The rock at the falls is a jointed gneiss, with segregations of black mica, chlorite with apatite, and glassy quartz with biotite. Waterworn pebbles are found high up the valley-slopes abreast of this place.

Some 10 miles down, the river is joined by the Mkushi, lying deep below the contiguous country, but with fairly soft slopes, which contrast with the 'new' appearance of the cañon-walls at the Lusenfwa Falls. Five miles onward the latter debouches into the Luano—falling over 1000 feet in its course from the falls.

It then heads straight across the Karroo floor for the inlier of Kasafa Mountain (Archæan), through a shoulder of which, some 500 feet above the plain, it passes by a deep and gloomy gorge.

The Malenji is situate to the west of the Lusenfwa, and is remarkable in that it emerges from a 'hanging valley' cut down about 300 feet below the escarpment-crest, whence it falls down the face of the precipice, or dip-slope of the gneiss, passing behind a ridge into a rocky defile. It flows only in the summer; and then its white cascade of over 800 feet, gleaming among the deep green foliage, presents a beautiful feature, visible from afar in the Luano Valley.

Farther west, again,—with many unknown streams intervening of a similar type,—comes the Kobwe, and then the Lungu. The latter gorge receives a waterfall, and runs into the deep cañon of the Molongushi, near its confluence with the Mwomboshi.

These three converging streams have been accountable for a considerable area of erosion, the waters passing into the Luano plain at Mount Jowlila. While the Lungu and Molongushi come over waterfalls and follow cañons cut across the strike of the gneiss, the Mwomboshi, as a contrast, belongs to the type that adheres to the strike of the cleavage, and its descent to the plain-level is in a gradual course for many miles.

The Molongushi River has the usual sluggish course in its plateau-reaches, and eventually passes through a range 3 miles north of the falls, formed of metamorphosed sedimentary strata. The country then feels the influence of the more rapid drainage over the plateau-edge, and becomes much broken by watercourses. It is among these forest-covered ridges that the thunder of falling water reveals, and attracts one to, the most beautiful of all these lateral cañons in the Machinga escarpment.

This of the Molongushi is about 1000 feet deep, and although the volume of water passing down is less than that of the Lusenfwa, —it nearly ceases in winter,—the cañon and surrounding features are deeper, wider, and grander. One is immediately struck by the repetition of the methods of degradation of the Machinga escarpment on the walls of this great cavity. Overhanging ledges and precipices are noticeable immediately near the falls, but the further parts of the gorge are more sloping, and the long streaks of white where landslips have torn down the trees in a descent that is generally complete from top to bottom, are evidence that the walls

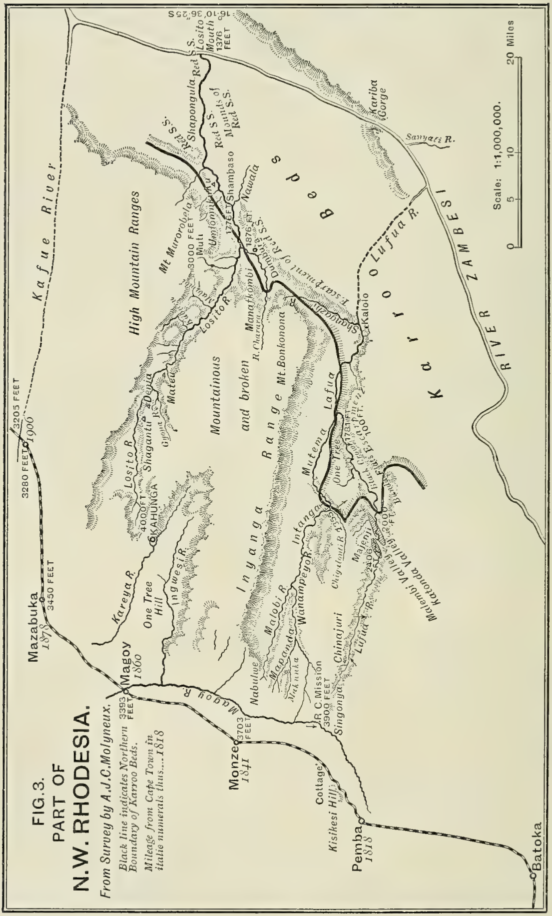


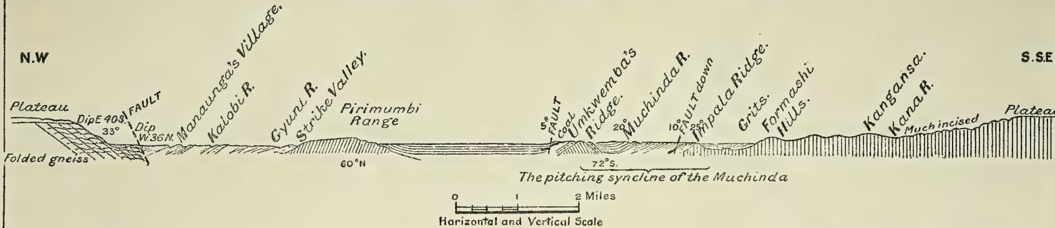
FIG. 3.
PART OF
N.W. RHODESIA.

From Survey by A. J. C. Molyneux.

Black line indicates Northern Boundary of Karroo Beds.

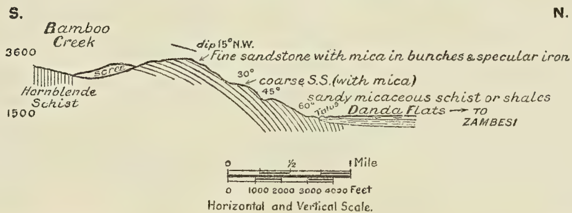
Mileage from Cape Town in italic numerals thus.... 1818

Fig. 4. Section across the Luano Valley on A-B. (See fig. 2, p. 412.)



[*For* 'Formashi' *read* 'Formoshi.']

Fig. 5. Section shewing descent to Danda flats (Southern Rhodesia side) opposite FEIRA



have not reached the constant angle of a natural batter. River-erosion, the prime cause, is thus still at work and undermines the base of the cañon, while subaërial agencies attack the verge and slopes. The formation is of gneiss, striking E. 7° N., dipping southwards 45° to 65°, and so jointed that the removal of titanic blocks by rains, river, and floods is greatly facilitated. These blocks, abraded to spherical shape, strew the path of the river in the cañon.

At a bend of the gorge a sand-river comes in from the east-south-east; it also has a wide, though stunted chasm. The junction is about 500 feet above, and 6 miles from, the outlet of the Molongushi to the Luano plain. That is, the gradual reduction of the latter basin has led to the erosion of this cañon exceeding 6 miles in length, and 1500 feet in depth, in order that the Molongushi River should accommodate itself to a new change of level. The causes that brought this about will lead us to discuss (pp. 430–35) the influence that structure, folding, and denudation have had on the surface-features or physiography of these wide regions.

The Danda Flats.

It has already been mentioned that the Zambesi river, between its junction with the Kafue and Feira, runs in a similar trough, or ' straits ', between the abrupt plateau-edges on each side. That on the southern side is well known to travellers on the path from Salisbury by way of Sipolilo's to Feira, when a descent of 2000 feet is made in about three times that distance horizontally.

At the back of this escarpment the plateau is made up of granite and hornblende-gneiss with east-to-west cleavage. Then the path rises rapidly over a pass of 3550 feet altitude, the rocky summits around being somewhat higher. This range is of pre-Karroo, fine, fissile sandstone, very micaceous and showing patches of specular iron—similar to and probably possessing affinities with the Chasonsa Series in North-Western Rhodesia. Great blocks of rock from the summits lie round about, and from here one enjoys a marvellous view of the river-flats far below, stretching away to the left and right, and across the Zambesi towards Feira, behind which the corresponding plateau of North-Eastern Rhodesia makes a hazy background.

In making the descent, it is seen that these ancient sedimentary rocks strike east and west, and gradually increase in dip from 15° at the summit to 60° and 70° at the base. At nearly two-thirds of the drop, the sandstone changes to a micaceous schist with augen-structure around the quartz. At the base the rock contains quartz in layers of an inch, and resembles the saccharoidal quartzites, which, on disintegration, give rise to screes of rubble at the hill-foot. The section in fig. 5 (p. 417) illustrates the arrangement of strata, but not of the contact with the Karroo beds that lie in the flats.

From the base the country comprises the remarkable Danda

Flats, made up of sandy loam and clothed with dense vegetation. Some 6 miles farther on, fine greenish and red sandstones appear in a creek, with a westerly dip of 5°, changing to a grey coarse deposit. At Jimkola's village and in the Hanyani River are beds dipping 10° southwards, made up of a fine buff sandstone, 100 feet thick, overlying 20 feet of conglomerate containing boulders of fine sandstone 18 inches in diameter. Under this is a grit, made up of quartz, granite, calcareous nodules, and micaceous sandstone, etc. from the escarpment; also shale and one piece of melaphyre were seen. The sandstone-boulders weather out easily and give rise to potholes. These beds seem to be of post-Karroo age.

The Angwa, near its junction with the Hanyani, is from 200 to 300 yards wide, with a sandy bed and many shingle-mounds. In ascending this, strata of Karroo characteristics are met: sandstones near the Anglo-Portuguese boundary form a river-cliff 30 feet in height, and at Nyamafega's they show current-bedding and potholing; they dip north-eastwards at 10°. In a creek near here are bluish shales and clays. Farther south, there are fine fissile sandstones (micaceous) with carbonaceous specks and ripple-markings, and harder compact beds, dipping 15°. The latter are jointed vertically, and water-erosion in a stream has widened the joints out, until the rock stands in columns 6 inches apart and 24 inches high.

From this point southwards there is a considerable development of sandstones, forming low hills that extend to the plateau-margins 15 miles away. The rock breaks into big blocks, and is frequently incised in deep kloofs by torrents.

I must now refer, as briefly as possible, to the margin of the Karroo deposits on the northern side of the Zambesi Basin, namely, around the Lufua and Losito Rivers, which join the Zambesi above its confluence with the Kafue. There again the escarpment-feature is in evidence, overlooking the valley towards the south, and extending, like a wall, far to the north-east. (See fig. 3, p. 416.)

The Lufua River.

From its source near the Monze Mission (altitude 3900 feet), this river takes an easterly course and deepens a valley, in Archæan rocks, 1250 feet before reaching the basin of Karroo strata 20 miles away. The unconformable base occurs on the slopes of a hill-side, and there is a succession of conglomerates and broad coal-measures, lying in a narrow basin a mile and a quarter long and 800 yards wide—in a cliff of which the strata are visible in Pl. XXII. This, the Malembi, is separated from a second and larger basin, the Katonda, by an anticlinal dome of gneiss, through which the Lufua passes by a 'poort.' Another similar dome divides this from the open Bonda Flats, and again there is a river-gorge.

The two valleys mentioned are due to two symmetrical folds

holding the soft Karroo strata, filled and even covering the anticlinal arches at the time when the course of the Lufua was determined. By erosion the clastic beds are being removed from the valleys, and the cutting of the intervening gorges proceeds *pari passu*. The evidence of folding is set forth later (p. 433).

The Intanga is a tributary of the Lufua, but its valley is strikingly different from that of the latter, and under its various local names might be looked upon as the true main river. It runs in an open and gradually descending valley, meeting the margin of the Karroo at an altitude of 500 feet over that of the contact in the Malembi basin, that is, 2855 feet—an unusual elevation for the Karroo hereabouts. The Intanga then passes through a rocky defile of gneiss to traverse a further basin of Karroo, and is there known as the Mutema.

Parallel and on its left bank is the Inyanga range, steep and high, which, viewed from a distance, possesses all the frontal appearance and features of the Machinga. This range merges towards the north-west into the Kahunga plateau, of which it is the typical abrupt escarpment-edge.

The Losito River is situate north-eastwards of the previous feature, and is the last valley that will be described as bearing upon the subject of this paper. Like the others it rises on the plateau, at 4000 feet, and quickly makes for itself a narrow gorge in the bedded Archæan rocks, striking east 23° south. Its valley-scheme resembles that of the Lufua, and it debouches on to the Zambesi Karroo plains through the escarpment-line near Muti Peak. The schists traversed by its upper course strike parallel with it, and anticlinal folds in the vicinity have axes pointing south-eastwards.

From the plateau-step the Losito meanders along the contact between the complex and the Karroo beds, the latter here dipping southwards. Opposite Murorobela Mountain it launches out for a course to the Zambesi, 18 miles away, traversing a flat, thorn-covered country, with much recent alluvium. Exposures of rock showed sandstones possessing lithological features that have much in common with the Forest Sandstone; and, if this correlation be established, we shall have here further evidence of the lowering of the Zambesi basin extending into post-Karroo times.

The Losito-Zambesi junction lies at 1376 feet above sea-level.

Generalizing the surface-features of the Lufua, Intanga, and Losito, I find that they are determined by structure, in that the valleys run parallel with the cleavage, the axes of folding, and the strike of the massive quartzites and limestones of the complex. These are the dominating causes of the Inyanga range. There is this variation from analogous causes in the Luano, that here they have a north-westerly and south-easterly direction instead of the east-north-easterly direction of the other.

The open character of the Intanga Valley and the high altitude at which the Karroo beds occur lead me to suspect a rising synclinal fold similar to the Muchinda, the limbs and head of which have been removed by erosion.

I have not traversed the Kafue gorge, but can recognize that it presents evidence of the radical change which is overtaking the drainage-system of the plateau. Above the railway-bridge (altitude 3205 feet) it meanders placidly over flats that seem to have no perceptible variations of level; but a few miles below it commences a rapid descent of the Zambesi 'trench', and falls 1755 feet in 20 miles.

III. The Karroo System.

I may now proceed to describe the rocks that build up the regions of the Karroo System in Northern Rhodesia, giving, first, a table of correlation based on investigations south of the Zambesi. Fossils found in these localities point to the Permo-Carboniferous age of the deposits, and include them in the Karroo System of South Africa. In the absence of discoveries of fossils from many beds, and, as the succession is conformable, the grouping has to be founded on lithological features or general relationship. The demarcation cannot, therefore, always be precisely defined.

Silicified wood in fragments, or in prostrate trunks as long as 9 feet, is found in all beds up to the Forest Sandstone. It would be interesting if specimens from the various horizons were carefully investigated, for they might be found to possess distinctions such as would give a key to the zonal stratigraphy of these regions, and one more reliable than lithological characters.

Cape Colony.		*Transvaal.*	*Rhodesia.*
Karroo.		Karroo.	Karroo.
Stormberg:	Volcanic Beds.	Volcanic Series.	Volcanic Series (Batoka Basalts, Tuli Lavas, etc.).
	Cave Sandstone.	Bushveld Sandstone.	Forest Sandstones (and Samkoto Sandstones).[1]
Beaufort.			Escarpment Grits and Upper Matobola Beds.
Ecca.		Ecca.	Lower Matobola Beds (and Coal Series).
Dwyka.		Dwyka.	Basal Beds and Boulder-Conglomerates.

[1] It will be seen that the position assigned to the Samkoto Beds, in my paper of 1903, is here altered, while the Sijarira Quartzites are left out, owing to the doubt as to their horizon since Mr. Lamplugh investigated the Deka Fault, Quart. Journ. Geol. Soc. vol. lxii (1907) p. 162.

The Basal Conglomerates.

Any discussion on Karroo areas leads to a natural enquiry concerning the existence of the Dwyka Conglomerate. So far, the most northerly claim for such occurrence is that at Palapye, in the Bechuanaland Protectorate, latitude 22° 40′ S.[1]; while Dr. E. T. Mellor[2] has lately found it along the Limpopo River. In Rhodesia basal beds possessing glacial features have not yet been recorded, and the contacts with the rocks of the complex are frequently found to be made by grits, coal-measures, or Forest Sandstones. This diversity shows the uneven nature of the floor on which the Karroo sediments were laid down. But Rhodesia has been shown by Mr. Newell Arber[3] to be included in the region of Suess's Gondwanaland, and it would be remarkable if this province alone can show no signs of glacial activity when other parts of the same ancient continent reveal them distinctly. Thus India has its glacial boulder-beds; Victoria, New South Wales, and Tasmania their Bacchus-Marsh conglomerates and glacial deposits; Brazil and Argentina their boulder-beds; and South Africa its Dwyka.

Yet it is notable that both Northern and Southern Rhodesia lie within 20° of the Equator, or in latitudes lower than that of the areas of glaciation of the other provinces of Gondwanaland mentioned. If, therefore, ice-action operated in these localities of the torrid zone, we might gather some idea of the compensating altitude above sea-level at which it occurred; while if it be absent, there would be the suggestion of a warmer climate than elsewhere, and a consequent question as to the causes that brought about a local amelioration of temperature.

In Northern Rhodesia there are coarse basal deposits of somewhat restricted distribution, but locally swelling out into wide masses. They never occur elsewhere than on the floor of the basin, in which respect they correspond with the Dwyka; and, although there is insufficient evidence of glacial origin, they possess features that distinguish them from true aqueous beds. It is probable that they were formed as 'screes' in the subaërial break-up of the uneven surface of the pre-Karroo complex.

A feature noticed by every one who has travelled in the Luano Valley is the existence of a surface-shingle of smooth and shining boulders and pebbles. They show in swelling mounds among the mapani forest, or lie in gravel-deposits under river-wash. They are conspicuous everywhere, and there is little of the area of the plain away from the alluvial terraces that has not a layer of shingle above or below the soil. Where this occurs on the surface, the

[1] A. J. C. Molyneux, 'A Contribution to the Geology of the Bechuanaland Protectorate' Proc. Rhodesia Sci. Assoc. vol. vi (1907) pt. ii.

[2] Mem. Transvaal Geol. Surv. No. 3, 1906.

[3] 'Catal. Foss. Plants of *Glossopteris* Flora in Brit. Mus. Nat. Hist.' London, 1905, p. xviii, &c.

pebbles subside into the ground and form a pavement that partly protects it from the scouring effect of the rains. Some such protected areas form hills as high as 300 feet above the surrounding country, while there is a sheet of shingle of some hundreds of square miles in extent on the eastern side of the Kasafa Mountains.

The pebbles are also a notable feature in the Luangwa Valley,[1] and they are to be seen in the Lukasashi 'trench'—thus ranging over a vast area, and claiming consideration as important material in the Karroo strata. It was noticed that each stone, however well rounded, was slightly dimpled with one or more faint concavities, and a careful examination showed this to be a distinctive feature possessed alike by those of walnut-size, boulders measuring 12 inches in diameter, and subangular blocks of 40 inches across—in the last-named increasing to more exaggerated cup or trough-like shapes. (See Pl. XIX.) These outlines could only have been gained by the submission of fragments to a process of crush-movement when the mass was in a semi-consolidated state, and before its complete and final settlement.

The search for the original rock resulted in coming upon the conglomerate, first as blocks in storm-channels, then *in situ* in the kloofs, and, lastly, up the plateau-slopes of Eakanunga Creek, on the north side of the Muchinda Valley, and some 350 feet above the centre of the plain, lying unconformably, with a dip of 10° to 12° towards the valley, upon the nearly vertical edges of gneiss.

Before describing this conglomerate and its distribution, it will be perhaps better to finish my remarks on the superficial shingle-mounds. By the transition of one to the other up the hillside, it is easy to see that they are derived from the breaking-up of beds, due to the rapid disintegration of the matrix. It will be shown that they still form the domes of anticlines in the flats, and probably bridged over parts of the promontories, rising to a height of many hundreds of feet above the present plain-level. The Archæan arches of these anticlines are now exposed; but the removal of the mass of conglomerate from the domes, and also from the limbs of the synclines, must have yielded immense supplies of pebbles. When the slopes were steep, the shingle would be carried down quickly; and thus, immediately below the line of the present exposure on each side of Eakanunga Creek, the foothills are formed of liberated boulders, pebbles, and the granular matrix or cement. (See Pl. XIX.) From the foot of these slopes the pebbles 'creep' towards the lower valley-plains, aided by the shifting nature of the clayey soil, and the effect of rains.

In this onward movement insects play an important part. Under each pebble is a maze of passages formed by all manner of burrowing insects (mostly ants), in the formation of which the excavated soil is dumped on the surface. This either becomes desiccated and

[1] L. A. Wallace, Geogr. Journ. vol. xxix (1907) p. 394.

blown away, or is removed by the first rainstorm; and, sooner or later, the pebble sinks downwards into the cavity formed by the insect. And, as there is frequently a steep fall to the surface of the ground, it moves onward.

There is thus a progression in a downward and onward direction; and if we consider that the disintegration of the rock-mass took place at as much as 1500 feet above what is now the valley-level (there are remains of the conglomerate at the head of the Muchinda Pass at that height), it will not be difficult to understand how the shingle has crept downwards into the valley without the aid of streams. Of course, storm-channels do help in the movement; but these shingle-mounds and sheets under the hillsides are mostly unsorted, the fragments being of all sizes just as when liberated from the mass.

Another point is that the surface-shingle retains its peculiar polish and shimmer in the sunshine, while pebbles to be found in the river-courses are roughened and 'frosted' by chipping together. Again, no pebbles of normal gneiss and schist are found among the derived superficial shingle.

We may return now to a description of the conglomerate *in situ*. This outcrop extends along the foothills of the Lupoposhwe range for a distance of 4 miles (that is, from Chigona on the east to the Kalungushi on the west), and is generally visible in small creeks. The Eakanunga is a V-shaped gorge cut down through the conglomerate and into the gneiss, which there dips steeply northwards. The right-hand cliff slopes abruptly southwards; and perched upon the top is the conglomerate, with many dislocated blocks, showing the unconformable contact. Masses of the rock fall into the creek below; and one such, 60 feet in circumference, is figured in this paper (Pl. XXIII), in order to show the arrangement of pebbles and the lenticular and fissile sandstone that may be found at irregular distances in the deposit.

At Chigona the conglomerate changes to an opaline grit, in which occur a few subangular white quartz-pebbles. Fresh fractures show a beautiful rose-pink matrix around sharp angular fragments of quartz of uniform size. The surface changes to pale greenish-grey, and the rock flakes slightly—cutting through grains and matrix alike. The cement changes on weathering to a whitish earth, and this may be the reason why it is mistaken for kaolin, and why certain Karroo opaline sandstones are looked upon as 'felspathic.'

On the opposite side of the Muchinda Valley—which corresponds with the southern limb of the syncline—there is much shingle along the foothills, including many boulders, and in positions that indicate their origin in masses of conglomerate, now reduced. East of the Rutente River are many blocks of it, lying on the shingle-talus; and up the hill-slopes I found small pieces *in situ*, adhering to the jagged edge of the quartz-schist, which there strikes east

and west and dips 45° southwards. One such piece, 3 feet across, was honeycombed, by the removal of the matrix from between the angular pebbles: an indication of how some of the mass may be broken up.

Other occurrences may be briefly noticed. Loose boulders and blocks of conglomerate may be seen in the Gyuni Valley, on the northern slopes of the Lupoposhwe divide, along a detached ridge parallel with the range, but divided from the Archæan rocks by a strike-valley 400 yards wide and 100 feet deep: this valley I take to be due to erosion getting to work behind the strike of the bed of conglomerate after the flat dome had been removed. This point is about 3 miles distant from the Eakanunga outcrop, and the intervening metamorphic ridge rises about 1000 feet—so that a low angle would take the conglomerate over the anticline.

In the Luano Basin, the coarse basal deposits occur also in a brecciated type:—angular unsorted fragments of the contiguous Archæan floor, almost as one may see them on the weathered surface nowadays. At Impala Ridge a dome of mica-schist emerges from the Karroo subsoil, and on its northern shoulder a dark red breccia (4 feet thick) is covered by a whitish micaceous clay, pipe-clays, and deep red ferruginous clay, breaking spherically into rounded blocks, bleached white near crevices invaded by tree-roots: these all dip 25° northwards. A similar breccia occurs at the base of the coal-measures at Chisali-sali Hills: consisting of unsorted fragments of the adjacent mica-schist, quartz-veins, schorlaceous schist, and white mica. The overlying sediments are tilted up, at an angle of 17°, against the metamorphic dome of Chisali-sali. This brecciated form, or 'scree' condition of the basement of the Karroo System may be observed at many other localities.

South of the Kafue River have been found masses of conglomerate, lying at the base of the formation in extensive patches, but seldom continuous for any great distance. In the Malembi syncline on the Lufua River, there is a siliceous conglomerate, with pebbles of angular quartz, and similar to the sharp fragments of vitreous quartz left scattered on the surface by recent decay of the schists. In the Chigalonti the contact is made by a 24-inch bed of saccharoidal quartz-conglomerate in a ferruginous clayey matrix; but at short distances on either side this bed is replaced by coal-measures, thus showing a very irregular floor.

Character of the Conglomerate.—The coarse basement-deposit of the Karroo seems to vary between an angular breccia and a well-worn rounded puddingstone. The former is a compacted mixture of fragments of mica-schist, angular vitreous quartz, and grains of hæmatite—with irregular patches of chocolate-coloured, sometimes greenish clay, and also of soft pellicles of sand. There is no sorting, orientation, or rounding, and the accumulation suggests a genesis similar to that of the weathering hill-sides of

the present day, where the schists rot for a considerable distance down. This primitive form is not thick, and may represent a land-surface.

Between this and the mature typical puddingstones there are many intermediate degrees of angularity, disposition of matrix, and arrangement. The Eakanunga type is rufous in colour, and shows remarkable diversity in short distances. Generally, the boulders lie without regard to size, and may be pressed close together with no interstitial matter, or separated by much matrix of varying fineness. The matrix changes in a few inches from angular grit to clay, while opaline silica (chalcedony) appears west of Chigona, making the rock extremely stubborn under hammer-blows: but it is rapidly reduced and softens on exposure. When the coarse matrix comes into contact with a pebble, the grains also become smooth on the contact-face. Among the pebbles there is an occasional semblance of orientation, with lenticles of hard false-bedded grit or fissile micaceous sand. The stones vary in size from peas to boulders of 40 inches, and consist almost solely of quartz and quartzite, partaking of the nature of the contiguous pre-Karroo rocks. Thus pebbles of banded ferruginous quartzite, schorlaceous rock, quartz with tourmaline, and saccharoidal quartzites, are all found near where those masses occur; while along the Formoshi range, which is of dolomitic schist, occur the interlaced quartz-prisms that originated from vughs therein.

It is noteworthy that fragments of gneiss, schist, dolomite, or limestone do not occur in any conglomerates where the pebbles are well rounded—only in the deposits that are brecciated, uneven, and show no evidence of internal movement. Some of these blocks would be removed in solution, while the gneiss and schist rapidly suffer disintegration under atmospheric waters. In a well sunk through a talus-sheet containing these rocks, the gneiss was found to be so soft that a penknife could be thrust into it. If therefore detritus of these yielding rocks were subject to pressure, the removal of the one description in solution, and the softening of the other, would cause such contraction in bulk that some movement would arise from that cause alone. If other forces were also at work, there would be increased grinding of the pebbles one against the other. In this manner the resisting quartzite-bands and vein-quartz would remain to form the pebbles, which would be pushed against each other, the nose of one into the side of the other, just as the Eakanunga conglomerate shows them now, and thus would be brought about the concave depressions that are to be found on every pebble.

Many boulders have a flattened surface or 'sole.' One was seen to have two flutings 4 inches apart between the crests and an inch and a half deep, running diagonally across the cleavage of the quartzite. Another block of 18 inches, otherwise angular, had a face for its whole length and breadth that was slightly concave and had sharp edges, and an egg-shaped one at Rutente had been cleanly cut across the end. These characteristics may all be

accounted for by the grinding together, even in the absence of ice. No other features that might be put down to glaciation were observed.

Strain-fractures and joints shape out the mass into blocks, and fissures pass through pebbles and matrix alike, resulting in clean-cut faces, over which quartz-crystals have grown. Parallel crush-cracks are induced for a few inches on each side, and cause the rock to yield an angular débris when it breaks up.

At Chigona the vertical joints run E. 10° S., the tabular joints dipping 10° east-south-eastwards. The dip is generally tangential to, and away from the domes of Archæan rocks upon which the conglomerates abut.

Among the basal beds of the system—those lying between the base of the Lower Matobola Beds and the floor—must be mentioned the unstratified red sandy clays at Chisalisali (Pl. XXI). They have many crush-cracks and small slickensides in all directions, the chief being to the west. They have an ascertained thickness of 100 feet, and are overlain by nodular concretions of hæmatite in definite bedding-planes, in an otherwise unstratified mass of red clays. These weather out in the bed of the Molongushi River in rounded masses, and the first river-floods of the summer are coloured pale blood-red by their decay. Similar strata occur under the coal-measures west of Kalilingoma, at Impala Ridge, and Muchinda Valley, containing pipe-clays, fibrous gypsum, and pisolitic ironstone.

The Lower Matobola Beds or the Coal Series.

These follow conformably upon the previous series. The whole succession of the coals and clays can be splendidly seen in the bed of the Molongushi at Chisalisali, where the river cuts across the strike for over 2 miles: the abrupt manner in which the coal-beds commence over the basal nodular clays is seen in Pl. XXI. The thickness is here 400 feet, and the seams of coal number upwards of 100—the widest being over 6 and 8 feet—and range downwards to a few inches only.

The coal is made up of laminæ of dull black shaly matter with bright shining coal—so numerous as to be almost microscopic. The latter frequently increase to as much as 3 inches in thickness, and as these parts contain only 3 or 4 per cent. of ash, their predominance greatly improves the economic value of the fuel. The dull layers seem, at first view, to be only shale, but their faces are covered with the powder known as 'mother of coal.' The bright matter splinters easily, and decrepitates on drying, fracturing in concentric rings or conchoidally. It has been known to yield balls measuring half an inch in diameter that weathered in concentric foliæ; while another specimen shows a number of discs, like the fractured ends of a bundle of thin pencils.[1]

[1] This structure resembles that of the Scottish 'eenie' coal, described by Messrs. C. T. Clough & J. Kirkpatrick in Trans. Inst. Min. Eng. vol. xxxvii (1909) pp. 2–11.

Coal-seams rop out over wide belts—generally where rivers, after leaving the regions of Archæan rocks, have cut courses for themselves along the tilted edges of the coal-measures, and in their meanderings expose first the lower and then the upper beds.

South of the Kafue, coal-beds crop out in the Lufua and Losito and their affluent streams at a great number of places. The series is there from 300 feet thick, dipping 5° to 12° south-eastwards.

Fossils.—The Lufua areas yield *Glossopteris indica*, and a shell of *Palæomutela*. In the Luano, *Glossopteris* and pith-casts of *Schizoneura* were obtained from a shaly bed near Chisalisali, and *Schizoneura* and *Gangamopteris* from Impala Ridge.

The Upper Matobola Beds.

This series has a minimum thickness of 2000 feet, and forms most of the area of Karroo deposits in the regions under notice. This is due mostly to the quicker dip of the coal-measures and lower beds along the margins of the basins, while the strata now to be described lie at low angles or horizontally in the central areas.

Describing them as seen in the Chisalisali outcrop, I would observe that there is no sharp change from the coal-measures below, but rather a gradual replacement of the coal-seams by beds of fine clayey sandstones, which in the upper parts assume a thickness of 30 feet. They are seldom laminated, but weather in potholes and along joints which, merging one into the other, give rise to grotesque forms. Current-bedding is frequent, and the particles are rather angular. Masses of this sandstone appear in the Zambesi, at the Lubu junction, potholing by currents in high floods.

They are divided by beds of the blue-grey unstratified clays, and among them are a few thin impure coals, with *Glossopteris*, sandy ironstones yielding *Estheria*, and limestones, both with cone-in-cone structure. There are also nodular ironstones (black band). Some more siliceous sandstones fissure transversely, and so break away in lozenge-shaped blocks. In the weathering of all these beds the unstratified clay goes first, and a section down the river-bed is much like the teeth of a saw.

The upper part of this series consists of more calcareous beds—layers of septaria among soft grey clay—the nodules weathering out into a very lumpy surface. Some measure 5 feet in length, and fracture irregularly, often semi-conchoidally, showing a steel-blue colour due to manganese. The nuclei contain no organic remains; but fluorspar and calcite (or arragonite) fill the crevices.

Some layers of fine sandstone, vertical-jointed, thin out laterally and may pass through the stage of a 'lime-nodule,' although they themselves are not calcareous, having perhaps been stripped of the lime by the growth of the nodule.

Up the Muchinda Valley are sheets of fibrous limestone with cone-in-cone structure, overlain by fine pulverulent sandstones, and resting upon clays. The limestone is interbedded with pale-green

clay in lenticles and pellets, which on removal leave flat almond-shaped cavities. The rock, on fracturing, shows a fibrous surface with a silky sheen. From nodules in the vicinity I obtained fossil ostracods, and a pink limestone, with clayey lenticles, yielded *Palæomutela.*

Earthy limestones at Manaunga's, close under the Machinga, yielded spines and teeth, bones, and unioniform shells.

The Escarpment Grits.

These are best seen at the south-western end of the Zambesi Basin—Sengwe and Wankie—where they present much greater development than farther north.

In the Luano the few noted areas of these deposits lie along the western side of the depression, near the Machinga wall and dipping towards it. Mr. Moubray informs me that they occupy such a position at Chipawa. I have seen them near the Lusenfwa gorge, Mashate's village, and at Manaunga's. At these last-named localities they form long red ridges parallel with the Machinga, with dip-slopes to the north-west. At Mashate's the ridge dies down to 40 feet in height, its upper part being of red grit, with angular fragments of quartz oriented, and placed at varying intervals. Under this is a mass of rounded pebbles and boulders, occasionally bedded, and generally unsorted. Boulders measuring 12 inches in longest diameter occur. The pebbles are of tourmaline-schist, quartz, quartzite, and gneiss: this last is soft and rotten, and there are other fragments of a soft ferruginous clay in which minute yellow quartz-veins exist. In this occurrence of soft pieces lies a difference from the basal conglomerates. From the latter such soft rocks would have been removed by the grinding movement—here a mere throwing-down in eddying currents was the only feature. There are no cracks, joints, or shearing visible.

At Manaunga's the ridge of these rocks lies about a mile from the foot of the plateau-wall, dipping 20° north-north-westwards. They overlie conformably the septarian clays, and comprise grits and hard red clays along a surface-belt of 4000 feet. The grits, with pebble-layers, weather soft in places, but elsewhere are more resisting. There was noticed a series of bands of grit, each 18 inches deep, with a layer of pebbles at the bottom, but passing upwards into fine current-bedded sandy clay—denoting some repeated condition of deposition.

The intercalated clays are hard, sometimes calcareous, deep red in colour, and weather in spherical blocks.

Low escarpments of the same type occur between the Losito and Lufua Rivers, where they form a line of red cliffs facing the Machinga.

The Forest Sandstones.

I have only noted the existence of the fine-grained rocks of this type in the Zambesi Plain, where the Losito River passes through cliffs, 30 feet high, of pink sandstones with current-bedding, and

again, along an outcrop of fine vermilion sandstones, with an interbedded white stratum. White concretionary siliceous kernels, or tubes of ordinary pencil size, also occur in the red beds. The dip is 10° south—conformable with the general dip thereabouts.

The altitude of these beds is about 1450 feet. Forest Sandstones cover the apex of the Matabeleland plateau at 4500 feet, where they dip northwards, but have overlapped the older Karroo beds and lie directly on the complex. The latest Karroo beds, the Forest Sandstones, thus seem to have shared in the depression of the basin in post-Karroo times. This supports Mr. Lamplugh's observations on the Deka Fault, which is marked by the downthrow of even later strata—the Batoka Basalts.

The Volcanic Series.

So far as my knowledge goes, this is not represented in the Lufua-Losito region or the Luano Valley, nor have any intrusions penetrated the Karroo strata.

The basalt-sheet, so remarkably developed around the Victoria Falls,[1] extends into Northern Rhodesia, as far as the slopes of the plateau about 30 miles from the river. Westwards it appears to stretch far up the Zambesi, in which direction there is much to learn as to the part played by this series in the physiography of the upper reaches.

The origin of the loose sand that overlies the basalt-sheet in rolling hills [2] (the 'Kalahari Sands' of Passarge) is probably in the saccharoidal quartzites of the Chasonsa Series of the complex. The associated limestones and schists are seen to contain the same granular quartz, and all these rocks weather to a great depth, yielding a sandy subsoil 5 to 10 feet thick. Such sandy areas, covered with wide-spreading forests, are of great extent in Trans-Zambesia, and the transport of the débris to the depressed sheet of the Batoka Basalts would not be attended with much difficulty.

IV. Structural Geology.

Post-Karroo Movements.

The rocks of the Karroo System are much fractured and jointed, and faults of varying amount of displacement are frequently encountered. At Chisalisali two nearly parallel faults have lowered a tongue of the upper sandstones into the coal-measures—a drop of 400 feet. The cracks show infilling of calcite in six parallel veins, each a quarter of an inch thick, denoting a succession of movements. These faults are radial, and cut across the strike.

The lines of greatest displacement, however, are tangential to the

[1] A. J. C. Molyneux, 'The Physical History of the Victoria Falls' Geogr. Journ. vol. xxv (1905) p. 400.

[2] G. W. Lamplugh, 'The Geology of the Zambezi Basin around the Batoka Gorge (Rhodesia)' Quart. Journ. Geol. Soc. vol. lxiii (1907) pp. 201–202.

Archæan inliers or anticlinal domes, and are probably due to the fracturing of the folds, by which the strata are thrown down in steps.

The tracing of the lines of the basal conglomerate leads to the recognition of certain important folds that materially affect the structure of the country, and offer an explanation of the deep Luano Valley.

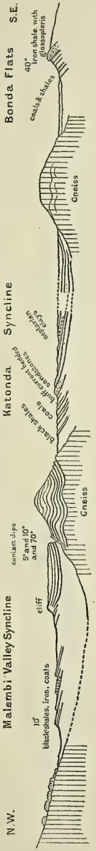


Fig. 6.—*Section showing the folding of the Karroo Strata on the northern margin of the Zambesi Basin.*

The Muchinda syncline has already been mentioned, and its northern limb described. On the other side, the conglomerates of the southern limb occur at the Umbelangwe, and along this range the beds dip northwards. Viewed from the front, both walls (the Lupoposhwe and the Changala) seem to tower up into the sky; but, if we stand on the strike of the basal beds, it is to find that the foothills slope $17\frac{1}{2}°$, and that the conglomerate dips at 10°, while a slope of 13° would carry the bed right up to the summit of the anticline towards the Gyuni. The last-named angle would climb any other part of the plateau-walls, if taken from the outcrop or contact—which is generally now some distance from the range proper, owing to the erosion of the transverse strike-valleys that were commenced while the lower parts of the mountains, at present bare, were protected by the conglomerate. On the Gyuni side of the Lupoposhwe dome $8\frac{1}{2}°$ would be all that is necessary. It is easy to forget that these mountains are really of small measurement in comparison with the distance of their summits, and it is of great importance that the explorer's sections should be drawn to the same vertical and horizontal scale if we are to appreciate the mountain-building effects of low dips.

The Muchinda syncline is gradually 'rolled out' towards the west, where the undulations die out on the flat plateau-level. This has the effect of bringing the Archæan floor up to the level of its limbs, and, conversely, deepens the deposits on it, towards the east. The Muchinda River follows the middle of the trough; its source is in the faintest depression on the plateau, 3700 feet, gradually deepening its valley until, at 12 miles, it is turned at right angles by the hill of Chilikutulu (altitude 3470 feet). On the summit of this are typical blocks, boulders measuring 18 inches in longest diameter, and shingle in profusion. The polish is gone, but they are cupped and dimpled, and consist

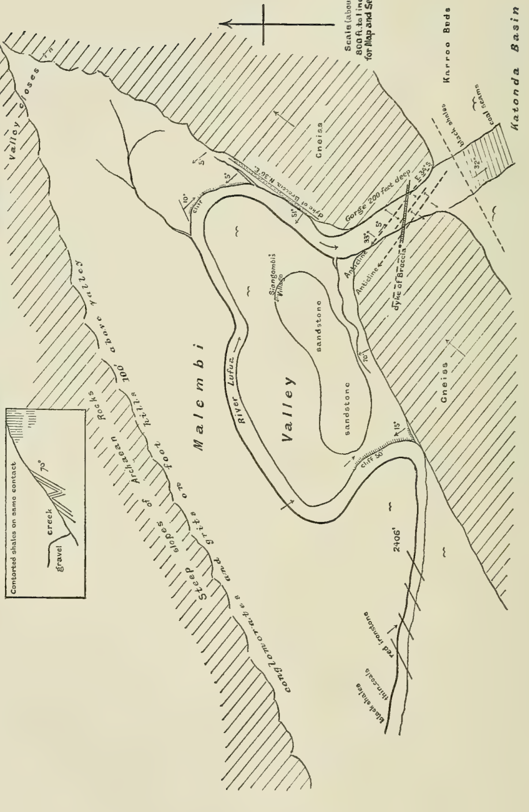


Fig. 7. Sketch Map of the Malembi Valley, Lufua R. N.W. Rhodesia

of quartzite, Chasonsa quartzites, and schorlaceous quartz. These contrast sharply with the dolomite upon which they rest.

This suggests some explanation of the course of other rivers from the southern plateau in valleys that are rocky defiles near the source, but afterwards descend in wide and open Karroo valleys. Compare the Lukasashi, Mwapula, Formoshi, and Kalobi, and the Losito and Intanga.

Parallel with the strike of the Muchinda are other folds, but of anticlines, such as the Formoshi divide; a small dome appearing in the flat, called Impala Ridge; and a low ridge near Umkwemba's village that extends for 5 miles, until it joins the big Kalilingoma Mountain.

At Chisalisali the beds dip away from the Archæan inlier, and also on the south-western spur of the Kalilingoma range; in the Mpupa Creek the shales dip north-westwards off the schists; and off the north-western side of Kalilingoma the sandstones dip tangentially away. The folds run in the same direction as the axis of the Luano Valley.

For another region of palpable folding—but, in this case, nearly at right angles to the strike of the gneiss—we can go to the Lufua River where it enters the Karroo area (fig. 3, p. 416; fig. 6, p. 431; & Pl. XXII). Here are three parallel but small trough-valleys of Karroo beds, separated by two ridges of Archæan rock through both of which the river passes by 'poorts' or gorges 200 feet deep. The first basin, the Malembi Valley, is about a mile and a quarter long by 800 yards wide, and the Karroo beds comprise a basal conglomerate on the north-western hill-slope, and a succession of coal-seams up to Upper Matobola Beds. The second basin, or Katonda, is wider and longer. The north-western limb shows coal-seams lying directly upon the pre-Karroo complex, followed by the Upper Matobola Beds, dipping 32° south-eastwards—a total thickness of 2000 feet. Across this flat the Lufua meanders, and passes through another anticlinal dome to the great Bonda plains of the Zambesi.

In this vicinity the pre-Karroo movements that gave a direction to the cleavage of the schists, and the axes of certain folds and cleavage, resulted in a north-west and south-east strike; and this direction is followed by all the rivers and by the Inyanga range (see fig. 3, p. 416).

The general arrangement of the Karroo strata is that they lie in synclinal basins. South of the Kafue is the wide mid-Zambesi basin: on its northern shores the beds are involved in the minor folds described, and then have a general southerly dip. But in that direction, and before the opposite limb rises up the Matabeleland plateau, there is evidence of other anticlinal arches at Wankie, the Sijarira Hills, the Lubu Gorge, etc., and the downthrow to the north by the Deka Fault. It may, therefore, be said that the mid-Zambesi area of Karroo is made up of a series of folds—the whole forming a great synclinal depression.

The Luano area is also constructed in the same way—a series of waves and step-faults that take the Karroo beds from plateau-level on the south, but differing from the mid-Zambesi basin in that it shows a general lowering to the north, terminating abruptly in a great fault, of 5000 feet at least, along the Machinga escarpment.

Pre-Karroo Movements.

The parallelism of the axes of the Karroo valleys with the cleavage and folds of the contiguous schists has been already mentioned. These fall into three directions:—

(1) East-north-east.—In this lie the course of the Zambesi trench from the Kafue to Feira, the Luano Valley, and several ranges of hills on the Basoli plateau that are shaped by escarpments of quartzite.

(2) South-east.—That of the Inyanga Mountains, and the flow of the Kafue, Losito, Intanga, and Lufua Rivers.

(3) North-east.—This is followed by the cleavage and folds in the Archæan rocks already noted, and is significantly the same as that of the great continent-building movements of South-East Africa. Mr. Lamplugh has suggested the possibility of the Deka Fault causing the broken edges of the Sijarira escarpment; while Mr. L. A. Wallace has put forward the fact that the Luangwa Valley and the mid-Zambesi are on the same line. I have shown that intervening regions have a similar trend.

It is thus certain that there is a zone of post-Karroo folding from the source of the Deka to the head of the Luangwa—a distance of over 800 miles, following the same axis of movements as those that commenced in pre Karroo times. And it is this north-easterly trend that influenced, first, the main plateau-axis of Rhodesia,[1] and secondly, its topographical features.

V. Physical History.

The lowest beds of the Karroo System were laid down upon an irregular surface, and it is possible that the present landscape had then, so to say, been sketched out. Of the thickness which the superimposed strata reached we can only estimate a minimum. In Southern Rhodesia it has been given as 4700 feet—in the regions now under notice it exceeded 3000 feet.

The Karroo deposits then became involved in tangential folding operating from a southerly direction, expressed in the anticlines and synclines already recorded, with some step-faulting, by which there was a general northward lowering in the Luano, southward in the vicinity of the Lufua, and north-westward at Sijarira.

The amount of the downthrow caused by the Machinga Fault

[1] See F. P. Mennell, 'Geology of Southern Rhodesia' Rhod. Mus. Report (1904) No. 2.

is difficult to determine. It is remarkable that the nearest high-veld deposit, north of the Zambesi, that can be claimed as being of the age of the coal series, is on the Kafue 150 miles away, and that nowhere on the plateau, in the vicinity of the slopes to the valleys, have I seen any vestige of Karroo beds. If they at any time extended over a vaster area, it is remarkable that they should, seemingly, have been cleared away so completely, for the blocks out of the basal conglomerate lying at the head of the Muchinda Pass show that this detritus is especially stubborn of removal.

But there is evidence that Karroo beds once existed up to the height of the escarpment, not only in the presence of the vestigial pebbles just mentioned, but in the manner in which erosion is now proceeding. The hanging valley of the Malenji, the course of the Lusenfwa through the Kasafa outlier, and of the Lufua and Intanga through the anticlinal domes, show that their courses were laid out when the land-surface was at a much higher level. Again, the narrowness of the belt behind the Machinga that is cut up by watercourses, the deep defiles of the rivers described, and the erosion of their gorges back into the plateau when viewed in contrast with their mature courses on the plateau, point to a time when there was no need for their sudden precipitation to any notable depth; and the presumption is that the high level extended across the areas of the Luano Valley.

How much higher than this level the Karroo beds reached cannot be stated, though it is probable that it was to some appreciable thickness, and that search on the plateau will one day reveal vestiges of these strata. For, subsequent to their deposition, folding, and faulting, the whole country was planed off to a peneplain of remarkable monotony, extending far away to the west, by which Archæan and sedimentary masses shared a common reduction to one level. By further causes, a radical change of the conditions under which the land was planed down took place; this subjected the areas of Karroo beds to differential erosion, by which process the synclinal folds of softer strata are being removed, to form the remarkable trench-valleys of to-day, while the pre-Karroo complex remains stubborn.

From these changes in the surface-level, some measure of the dislocation of strata by the Machinga Fault may be ascertained. The Karroo beds at the base of the escarpment are those of the latest series that is now displayed in the Luano, the Forest Sandstones being wanting. The system is at least 3000 feet thick, and to this must be added the depth (2000 feet) of the Machinga wall.

But the planing of the peneplain may have removed a further thickness, and the total of the two figures just mentioned, namely 5000 feet, for the downthrow of the Machinga Fault, falls short of the probable dislocation.

Of the subsequent erosion of the clastic beds in the mid-Zambesi Basin and the Luano Valley much may be said, and the means by

which it is facilitated are described in the following section of this paper (§ VI). The area of these regions, and of the Luangwa Valley, where probably the same general conditions exist, is some 30,000 square miles; and, when it is mentioned that from 1000 to 2000 feet of superimposed strata have been removed since the last elevation of the plateau, this conveys a mere hint of the potency of the erosive forces that have been and are still at work.

VI. Subaërial Decomposition in the Luano.

In the degradation of the Karroo deposits of the Luano Valley, rivers and storm-courses have cut down the overlying beds to a fairly even plain; indeed, it is remarkable that there are no deeply incised gorges or high hills (except the Archæan inliers), as one might expect in areas that are subject to much erosion.

This is explained by the complete absence of strata that possess any powers of resistance, such as the effusive basaltic sheets that cap other areas, or the massive sandstones of the Sengwe and Wankie districts. There are some siliceous and calcareous deposits that are tough when freshly excavated; but, generally, atmospheric decay brings about rapid disintegration, and any rocks that crop out are soft and friable.

Towards this removal of the beds much is due to decay of the rocks *in situ*. Where there are flat areas of unstratified clays or argillaceous sandstones, the surface, generally covered by mapani trees, soddened in summer and turned to a clinging mud by the heavy rains that hardly find a drainage-slope, dries up during the general desiccation in the seven dry months of winter and forms a maze of cracks, nearly as wide as a man's boot, and thinning downwards for 50 feet. In addition, deeper clays dry up, and pulverize into fragments. Down the cracks the air, moisture, and acids, derived from the rotting of surface-vegetation, penetrate, and by these means the original structure of the rock is lost, calcareous or ferruginous strata are converted into a loose sand, and the clays into a friable mass. Grass and tree-roots aid in the general reduction. Carbonaceous beds seem to suffer most, for the percolating agents act on the pyrites; and, heat resulting naturally from the chemical change, expansion takes place, which twists the stratum or brecciates it, and even brings about slickensiding movements in the superincumbent deposits. When decomposition is complete and the soluble contents are removed, the bed shrinks, and subsidence takes place.

In this way, areas of soft material are formed, and it will be realized that they fall a ready prey to fluviatile erosion. At times these sink into saucer-like depressions, to be puddled even deeper by wallowing animals when storm-water collects. Frequently also, the desiccation-cracks develop into drains and undermine the surface in a chain of gaping holes, eventually to declare themselves

as the head of a storm-course or kloof trending towards the river. Shafts of 100 feet sunk in this formation often show a complete rotting to that depth.

These soft masses fall an easy prey to the meanderings of the rivers, which quickly overtake the slow process of atmospheric decay. On the river reaching the unaltered rock the true nature of the Karroo strata can be seen, and it is difficult to realize that the one is but the original form of the other. Coal-seams then form conspicuous steps, and the sandstones wear into potholes and other grotesque shapes.

The transitions undergone by a coal-seam are remarkable. When subjected to subaërial alteration, it appears as an evenly laminated grey shale, of a faint amethystine colour. In the bedding is a reddish or black dust, sometimes so arranged as to be suggestive of plant-structure. The streak-powder is fine, and sharp to the touch. Frequently the shaly structure disappears, and a brecciated appearance takes its place. As the seam is followed from the outcrop, improvement in commercial quality is marked by a browner colour and a blackening of the bedded dust. Next a yellowish efflorescence shows in the cracks, then an appearance of specks of dull brittle coal, increasing into laminæ, with 'brassy' pyrite and vertical films of calcite. These improvements are but gradual, and the good coal is only reached at 100 feet from the surface by vertical sinking; but the percolation, which is easier along the dip of the seam than through the roof, extends along the bed for over 300 feet from its outcrop.

VII. Conclusion.

In this paper I have tried to describe the local facies, at widely separated localities, of the Karroo beds in Southern Rhodesia, deeming that from them we may learn much of the powers that have operated, and their results, over an extensive region of South Central Africa.

In conclusion, I desire to express my thanks to those who have so kindly afforded me advice and help, especially in the discussion of points by correspondence, namely, Prof. Grenville A. J. Cole, F.G.S., Dr. A. Smith Woodward, F.R.S., and Mr. Herbert Kynaston, F.G.S.; but to Mr. G. W. Lamplugh, F.R.S., is my gratitude more especially due. Mr. S. F. Townsend, Resident Engineer of the Rhodesia Railways, very kindly permitted me to use maps and altitudes; and I have to thank Dr. Walcot Gibson, F.G.S., for his recommendations in the drawing up of this paper. Dr. J. S. Flett, M.A., and Prof. Grenville Cole have obligingly gone to considerable trouble in examining my rock-slides, but much of the valuable information given to me touches upon the pre-Karroo complex, and is therefore felt to be beyond the scope of the present paper.

EXPLANATION OF PLATES XVII–XXIII.

Plate XVII.

Map showing areas of the Karroo System in Northern Rhodesia, on the scale of 80 geographical miles to the inch.

Plate XVIII.

Conglomerate, Chigona Creek (Lupoposhwe divide), showing juxtaposition of boulders; looking north-eastwards.

Plate XIX.

Disintegrated conglomerate forming the foothills west of Eakanunga Creek. (See p. 423.)

Plate XX.

Conglomerate *in situ* on the southern foothills of Lupoposhwe. Dip southwards.

Plate XXI.

Molongushi River: basal clays and nodular ironstones, overlain by coal-measures. (See pp. 414, 427.)

Plate XXII.

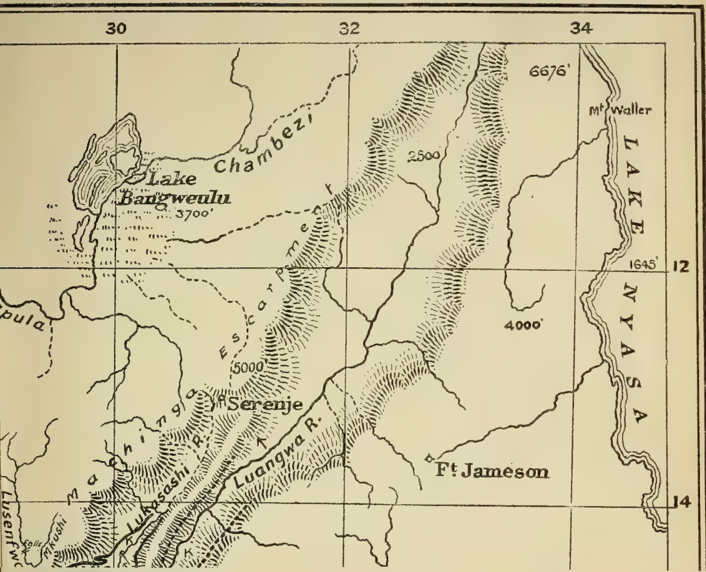
The Malembi syncline from the north-west, Karroo beds showing in the white cliff. See pp. 419, 433; also text-figs. 6 & 7 (pp. 431 & 432).

Plate XXIII.

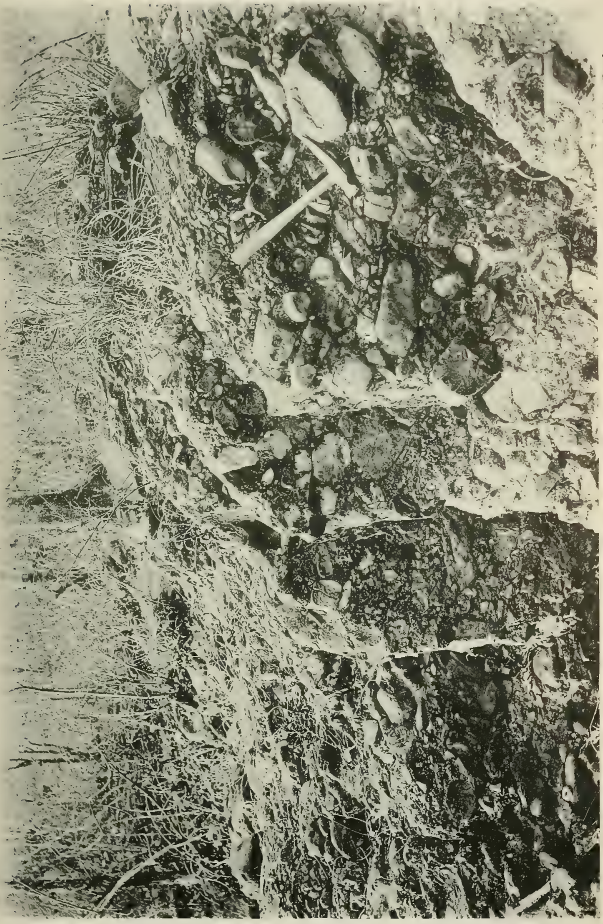
Fallen block in Eakanunga Creek, looking south-westwards. (See p. 424.)

Discussion.

Mr. Lamplugh congratulated the Author on his notable addition to our knowledge of the structure of South Central Africa, and regretted that there would be no time to discuss the many interesting points raised by this paper. It was fortunate that the Author had been able to investigate a particular district in this wide country somewhat closely, instead of having to depend for his information entirely upon wide-spaced traverses. The Luano depression appeared to be essentially similar to the remarkable features described as graben in South-East Congoland, some 350 miles farther north, having nearly the same direction. But it appeared that the Luano lowland was bounded by a master-fault on one side only, while on the opposite side the undulating Karroo beds of the floor were carried irregularly up the slopes by the rise of their dip. Though the impressive Machinga escarpment was due in some degree to the stripping-away of the Karroo sediments, its physiographic features, as the Author had shown, strongly suggested that it marked the line of a still-growing fault which had its highest value on the north-east, and had gradually broken backwards or south-westwards into the heart of the plateau along the synclinal fold.


30
32
34
6676'
Mt Waller
LAKE NYASA
Chambezi
Lake Bangweulu
3700'
2500
Escarpment
1645'
12
4000'
5000
Serenje
Luangwa R.
Lukasashi R.
Ft Jameson
14
Mkushi
Falls

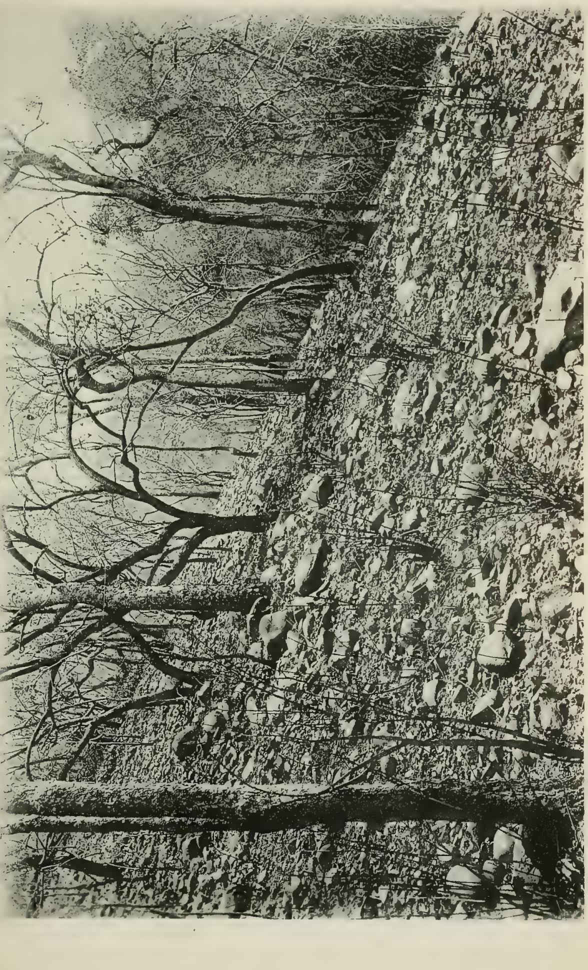
[Karroo System shown thus: K. Numerals denote altitudes in feet.]



A. J. C. Molyneux, Photogr.

Bemrose, Collo., Derby.

CONGLOMERATE, CHIGONA CREEK (LUPOPOSHWE DIVIDE),
SHOWING JUXTAPOSITION OF BOULDERS: LOOKING NORTH-EASTWARDS.

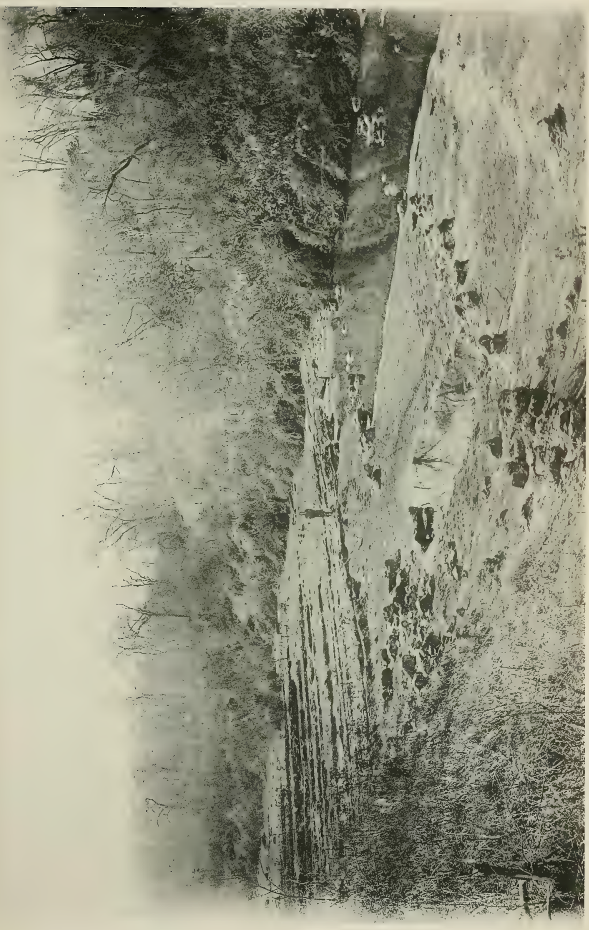


A. J. C. Molyneux, Photogr. *Bemrose, Collo., Derby.*

DISINTEGRATED CONGLOMERATE, FORMING THE FOOTHILLS WEST OF EAKANUNGA CREEK.

A. J. C. Molyneux, Photogr. Bemrose, Collo., Derby.

Conglomerate in place on the Southern Foothills of Lupoposhwe: dip southwards.



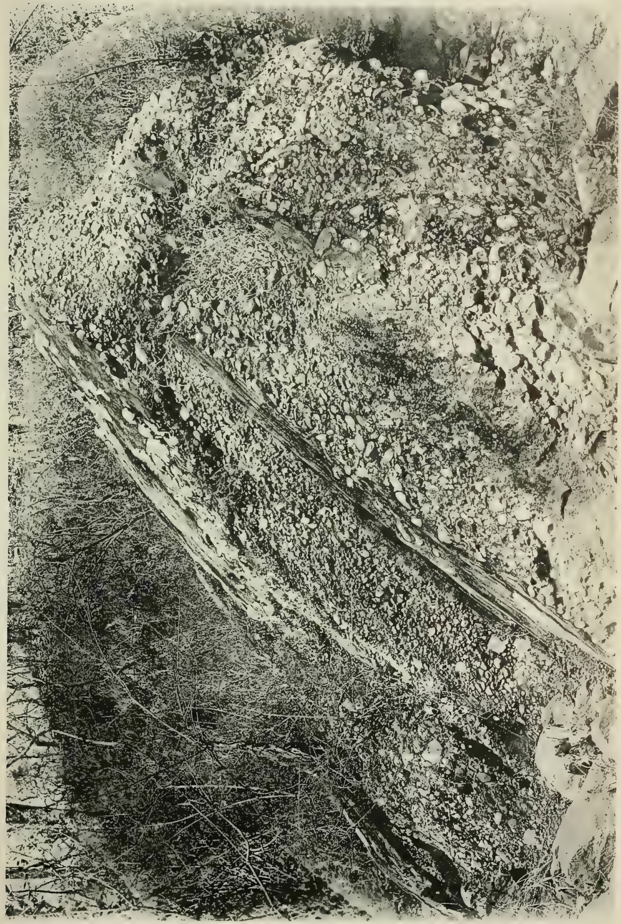
A. J. C. Molyneux, Photogr. *Bemrose, Collo., Derby.*

MOLONGUSHI RIVER: BASAL CLAYS AND NODULAR IRONSTONES OVERLAIN BY COAL-MEASURES.

A. J. C. Molyneux, Photogr. Bemrose, Collo., Derby.

The Malembi Syncline from the north-west: Karroo Beds showing in the white cliff.

(See also text-figs. 6 & 7.)



A. J. C. Molyneux, Photogr.

Bemrose, Collo., Derby.

FALLEN BLOCK IN EAKANUNGA CREEK, LOOKING SOUTH-WESTWARDS.

Mr. H. B. Maufe took exception to the term graben being applied to those valleys described by the Author which did not seem to be due to trough-faulting.

Dr. J. W. Evans reminded the Fellows that the Lower Gondwana coalfields of India, which corresponded in age to the Karroo beds, were similar in structure to the outliers of the latter described by the Author, being bounded on one side by a powerful fault towards which the strata dipped. He also suggested that the progressive decrease of the gorges from north-east to south-west might be due to a diminution of the rainfall in that direction, instead of a progressive extension of the faulting.

Dr. F. H. Hatch said that it was not apparent from the brief reference that had been made in the paper to the 'Fundamental Complex,' which in places was also described as Archæan, how much of the South African succession that expression was meant to cover. He wished therefore to ask whether the Author had found any evidence for the existence in Northern Rhodesia of one or more of the great sedimentary and volcanic systems which in the Transvaal and Cape Colony occurred between the oldest schistose formation and the Permo-Carboniferous Dwyka, and possessed a total thickness of at least 50,000 feet, without counting the gaps represented by several great unconformities.

Mr. A. R. Andrew said that he had no personal knowledge of the Author's districts, but had some acquaintance with the country near Lake Nyasa. With regard to the basal conglomerate in the Luano Valley, the Author had mentioned boulders of quartz and quartzite only, none of gneiss. In two instances in Nyasaland, where he believed he had found a basal conglomerate, the majority of the boulders were of gneiss. He congratulated the Author on his paper.

The Author expressed his thanks for the manner in which the paper had been received. Answering Mr. Andrew, he stated that gneiss- and schist-fragments only occurred in the brecciated basal deposit, not among the conglomerate which was made up of smooth pebbles. As to Dr. Hatch's question, he included such limestones and quartzites as were found among the rocks of the complex under the category of pre-Karroo.

23. *On some* Reptilian Remains *from the* Trias *of* Lossiemouth (Elgin). By D. M. S. Watson, B.Sc. (Communicated by Prof. W. Boyd Dawkins, D.Sc., F.R.S., F.S.A., F.G.S. Read June 16th, 1909.)

[Abstract.]

The fore limb of *Ornithosuchus woodwardi* is shown in a specimen in the Manchester Museum. It is small, only about one-half the size of the hind leg. The scapula is much expanded at both ends, and is indistinguishably fused with the coracoid. The latter bone is pierced by a large foramen. The humerus is a slender bone, somewhat twisted, but not much expanded at the ends; it has a distinct ectepicondylar groove. The ulna is very broad at the proximal end, but narrows distally; its proximal portion forms a thin plate of bone. The radius crosses the ulna, its proximal end lying entirely in front of it, while the distal ends of the two bones lie side by side. The carpus cannot be made out. Only metacarpals 1, 2, and 3 are functional; but a possible representative of 4 lies closely pressed to the back of the other three. Both phalanges of digit 1 are preserved, the last being a strong claw.

Ornithosuchus is restored as an animal walking on all fours, with the head carried rather low. The proportions are identical with those of *Ætosaurus.*

A description is given of the skeleton of a very small reptile, interesting as recalling *Ætosaurus* in its armour, and because it shows the whole of the animal except the tail.

24. *On some* Reptilian Tracks *from the* Trias *of* Runcorn (Cheshire). By D. M. S. Watson, B.Sc. (Communicated by Prof. W. Boyd Dawkins, D.Sc., F.R.S., F.S.A., F.G.S. Read June 16th, 1909.)

[Abstract.]

Very little information exists as to the tracks of the smaller reptilia of the Trias, although several types of footprints have been described from isolated examples. Four types of tracks which occur on the slab of sandstone from Weston Point, described in 1840 by Dr. Black, are discussed in this paper. They belong to forms generally included in the Rhynchosauroid types and to the footprint I, Beasley.

Both pes and manus are impressed in three of the cases, the other being so small that it is doubtful whether the manus would have made a recognizable impression if it did touch the ground.

Footprint A 2, Beasley, has a manus very similar to the pes, but showing some traces of the palm.

Footprint A 8, spec. nov., has five toes in the pes connected by a web. The manus is also five-toed, but corresponds to some extent to I, Beasley. There is a well-marked tail-streak in the track.

E, Beasley, which is very similar to I, really has five digits, the fifth being directed backwards and only just touching the ground.

A very small footprint is described as A 9.

It is suggested that some of these prints may quite well belong to such Thecodonts as *Ornithosuchus*.

25. *On the* Anatomy *of* *Lepidophloios laricinus*, Sternb. By D. M. S. Watson, B.Sc. (Communicated by Prof. W. Boyd Dawkins, D.Sc., F.R.S., F.S.A., F.G.S. Read June 16th, 1909.)

[Abstract.]

A specimen of *Lepidophloios laricinus*, found in one of the coal-balls of Lancashire, shows the internal structure. The species is new, and is of the ordinary lepidodendroid type, but is remarkable for the great size and strength of the corona and the leaf-traces.

Lepidophloios acadianus, Dawson, which is identical with *L. laricinus*, appears to differ in its internal structure, in having still stronger protoxylem-points and leaf-traces.

Lematophloios crassicaule, Corda, which is *L. acerosus*, L. & H., appears to resemble greatly the Lancashire specimen of *L. laricinus* in its structure, and is quite distinct from the specimen of the same form described by Cash & Lomax.

Lepidodendron fuliginosum, Will., a structural species, appears to include a specimen the external structure of which corresponds with *Lepidophloios acerosus*, *Lepidodendron obovatum*, *L. aculeatum*, and *Sigillaria discophora*.

Under these circumstances, it is proposed to take no account of the impression-species in considering the synonymy of the structural specimens, and *vice versa*. When the exterior of a structural specimen is actually known, it may be referred to by the name of the structural species, with that of the impression-species added in brackets.

26. *On the* Geology *of the* Neighbourhood *of* Seaford (Sussex).

By James Vincent Elsden, B.Sc., F.G.S. (Read May 12th, 1909.)

Contents.

I. Introduction.

The following paper deals with that part of the South Downs which adjoins the coast between Beachy Head and Newhaven. Its primary object was to investigate the variations of the dip and strike of the Chalk strata in that area, with the view of discovering the interpretation of the sudden westerly dip of the Chalk at Seaford Head. Incidentally, the geological features of the surrounding country and their relation to the surface-contours are discussed, and reasons are given for the view that the true eastern extremity of the structural area known as the Hampshire Basin lies within this district. With regard to previous literature on this part of Sussex, the whole question is summed up by Mr. Jukes-Browne in the following statement, published in 1904:—

> 'At Newhaven the beds are nearly horizontal, so there must be a quick recovery from the steep inclination which they show in Seaford Head. Whether they are re-curved or faulted we have no means of knowing.' [1]

Previous knowledge of the Chalk stratigraphy of this particular area is, in fact, limited to Dr. Rowe's detailed researches on the cliff-section.[2] It should be stated, however, at the outset that, without the assistance derived from Dr. Rowe's paper, it would not have been possible to carry out this investigation; for the results depend entirely upon the zonal criteria established by him, and their application to the practical work of mapping the inland outcrops of the higher Chalk-zones exposed in the cliff-section of Seaford Head. This method seemed to be the only way of arriving at a solution of the problems hereafter to be discussed. For, although the lithological characters of these zones are often fairly well defined, they are not alone a sufficient guide for the purpose of fixing boundary-lines in the field, and it is therefore necessary to rely mainly upon direct palæontological evidence.

The area in question is drained by the Ouse and the Cuckmere.

[1] 'The Cretaceous Rocks of Britain' Mem. Geol. Surv. U.K. vol. iii (1904) p. 39.

[2] 'The Zones of the White Chalk of the English Coast: Part I—Kent & Sussex' Proc. Geol. Assoc. vol. xvi (1899–1900) pp. 289–368.

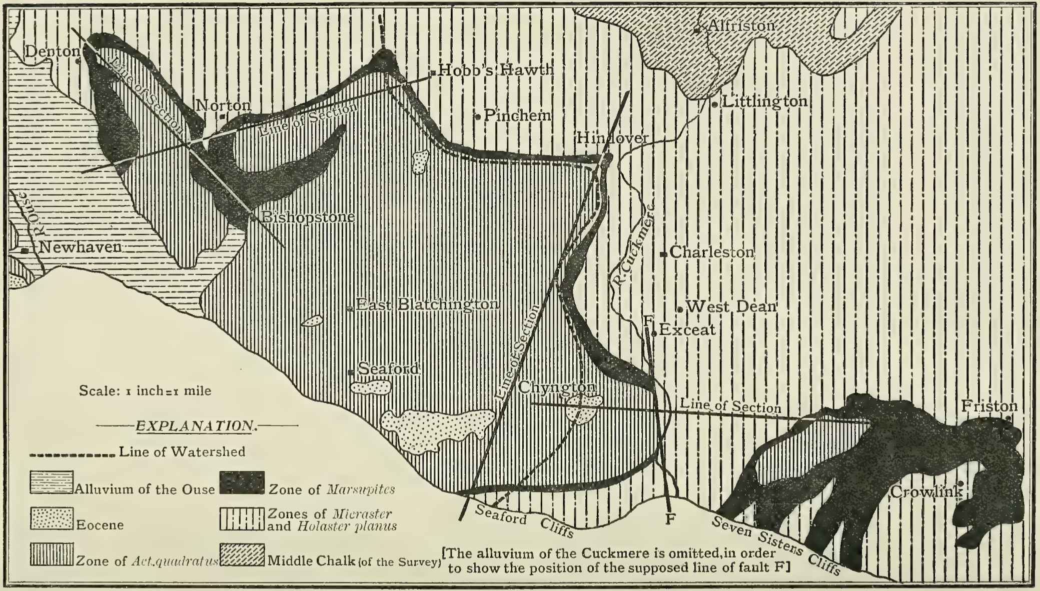
Its physical features are illustrated by the accompanying diagram (fig. 8, p. 456) photographed from a model, on the scale of 6 inches to a mile, made for the purpose of this paper. Attention will be drawn at a later stage to certain of these features, which will be more intelligible when the stratigraphy of the country has been explained.

II. Stratigraphy.

It is almost needless to say that this area does not differ from the rest of the Sussex Downs in the scarcity of good inland exposures. The few chalk-pits that exist are mostly overgrown, and large stretches of bare turf, with few exposures of any kind, except such as have been caused by small slips and rabbit-burrows, increase the difficulty of mapping outcrops. For this reason I confined my efforts to tracing the boundaries of the zone of *Marsupites testudinarius*, the limits of which are so clearly defined in the cliff that some measure of success seemed to be possible inland. Moreover, the delineation of the boundaries of this zone enables the overlying zone of *Actinocamax quadratus* to be completely mapped throughout this district, and of course indicates also the upper limit of the underlying zone of *Micraster cor-anguinum*. By this means sufficient evidence is afforded of the general stratigraphy of the district.

Attention is first directed to the region east of the Cuckmere. We know from Dr. Rowe's work that the *Marsupites*-Zone in the cliff-section occupies the summits of four of the Seven Sisters lying nearest to the river: so far as I can ascertain, the accuracy of this conclusion admits of no doubt. Inland I have traced this zone as far eastwards as the Birling Gap Valley, and it terminates on the north in the long valley running from Jevington below Friston towards West Dean. The zone occupies, in fact, the summit of an eroded plateau which stretches between Friston and Cliff End at the mouth of the Cuckmere. The main evidence for this conclusion I will recapitulate briefly. All round the Crowlink Valley the *Uintacrinus*-Band can be distinguished. It occupies the highest contours on the east of that valley, and is soon lost on descending the hill towards East Dean. A good exposure of this band is seen in an old pit on the hill-top due east of Crowlink Farm, where the typical fossils can be collected. The bed seems to be dipping very slightly towards the west, since it occurs at a somewhat lower level on the western side of Crowlink Valley about a mile away. That this bed terminates near Friston is indicated by a good exposure below the windmill, facing west, where the top of the zone of *Micraster cor-anguinum* is indicated by characteristic fossils, among which the large form of *Conulus albogalerus* occurs in some abundance. I shall have occasion to refer again to the occurrence of this fossil in a band at the top of the zone of *Micraster*

Fig. 1.—*Geological map of the neighbourhood of Seaford, on the scale of 1 inch to the mile.*



cor-anguinum, as this is one of the rare cases in which the fossils of the inland outcrops are not apparently in strict agreement with those of the cliff-section. Only the higher ground due south of Friston is occupied by the *Marsupites*-Zone, which does not, therefore, show itself in the cliff-section east of Crowlink.

Distinct evidence of the *Marsupites*-Zone is also found in the hill above Exceat New Barn, where *Uintacrinus*, *Terebratulina Rowei*, and several specimens of the large flat form of *Rhynchonella plicatilis* were found. A pit here is probably near the top of the *Uintacrinus*-Band, for just over the ridge, in Limekiln Bottom at nearly the same level, plates of *Marsupites* occur in fair quantity, immediately below the 300-foot contour. Several old pits occur round Limekiln Bottom, and I was told that lime-burning was formerly carried on there. Most of these pits extend downwards into the *Marsupites*-Zone, but they are now largely overgrown.

It is easy to link up the evidence thus obtained with that of the cliff-section. Although the northern edge of the plateau is less satisfactory from the point of view of exposures, there is sufficient evidence to show that the *Marsupites*-Zone occupies all the higher ground between Friston and Cliff End. There is, however, a thickness of Chalk above the lowest part of the *Uintacrinus*-Band, which is too great to be thus accounted for. Moreover, above the level of the highest occurrence of *Marsupites* there is distinct evidence of the passage-beds characterized by an abundance of *Ostrea wegmanniana*, bryozoa, and *Rhynchonella plicatilis*. There still remains a thickness of nearly 50 feet on the highest part of the plateau, which must therefore belong to the zone of *Actinocamax quadratus*. Thus this plateau is capped by *Marsupites*-Chalk, with a thin covering of *A.-quadratus* Chalk at the western end. The beds lie with so slight a westerly inclination that they appear to be nearly horizontal. The actual change in level of the *Uintacrinus*-Band between Crowlink and Cliff End, a distance of about 2 miles, is approximately only 100 feet, giving a very small angle of dip in this direction.[1]

The lower slopes between Cliff End and Exceat Farm are in the zone of *Micraster cor-anguinum*. A pit near the sharp easterly bend of the river, close by the Farm, yields very characteristic fossils, including the name-fossil in abundance and large valves of *Inoceramus cuvieri*. The flint-lines are nearly horizontal here and elsewhere along the valley on this side of the river, as far as Cliff End. This approximate horizontality of the beds on the east side of the Cuckmere is important to note, in view of what follows.

Proceeding to the west side of the Cuckmere, some initial difficulty was experienced in finding an inland outcrop of the *Marsupites*-

[1] The cliff-section in Dr. Rowe's paper, drawn by Mr. C. Davies Sherborn, indicates a slight rise between Crowlink Valley and Cliff End, and there may be a transverse undulation in addition to the general dip. To this further reference is made on p. 453.

Zone. Traverses were first made for the purpose of determining the northern extension of the zone of *Actinocamax quadratus*, which is readily traced from the west of Seaford Head northwards to the top of Hindover, immediately beneath which, on the south side, the Bryozoa-Bed is strongly marked. By a systematic examination of the beds in the Cuckmere valley, from Alfriston towards the south, it was soon found that the key to the position of the *Marsupites*-Zone lay in the steep slope of Hindover, where, despite the absence of really good exposures, numerous small slips in the Chalk afford fair opportunities for collecting at successive horizons. This section gave me much trouble, but the sequence finally proved to be as follows:—The upper part of the northern face of the slope, about 75 feet in depth, as measured by the aneroid, is in the zone of *Actinocamax quadratus*. The evidence is quite complete; *Cardiaster pillula* and the gibbous form of *Echinocorys scutatus* occur, and near the base the passage-beds with bryozoa and the *Ostrea-wegmanniana* Band are recognizable. A few feet below this plates of *Marsupites* are to be found in quantity. Lower still may be recognized the *Uintacrinus*-Band; and the top of the zone of *Micraster cor-anguinum* is again distinguished by a well-defined band of *Conulus albogalerus* and other characteristic species. A similar sequence can be identified on several traverses of this hill. The top of the *Marsupites*-Zone is here at a height of about 225 feet above the river.

The outcrop of this zone can now be followed westwards along the steep face of the deep dry valley in which are situated Pinchem and Hobb's Hawth. This valley for some distance follows the general strike of the Chalk, but winds northwards as it approaches the watershed. In consequence, the outcrops rise in level along the valley, and the *Uintacrinus*-Band crosses the watershed at an altitude of 300 feet. This fact was readily proved by finding *Uintacrinus* and *Terebratulina Rowei* in some rabbit-burrows just below the ridge at that altitude. The bottom of this valley throughout is in the zone of *Micraster cor-anguinum*, typical fossils occurring in numerous small exposures near the base. The whole of the ground sloping southwards, between this valley and the sea, is in the zone of *Actinocamax quadratus*, all the available openings yielding unmistakable evidence of this horizon.

Passing over the watershed westwards along Beacon Hill, direct evidence is scanty, owing to the scarcity of good exposures. The configuration of the ground, however, shows that the outcrop of the *Marsupites*-Zone should follow the steep face of Beacon Hill towards the west, until the bold north-and-south ridge, extending from Denton to Bishopstone, is reached. This ridge is best attacked, in the first instance, on the western flank. At Denton village a chalk-pit in the lower part of the hill again shows the *Conulus-albogalerus* Band, which, as at Friston and Hindover, marks the top portion of the zone of *Micraster cor-anguinum*. This zone is

also indicated by other fossil evidence. Similar results are obtained in several other exposures round the base of the hill, both in Poverty Bottom and on the western face of Mount Pleasant. On the top of the hill another pit shows clearly the zone of *Actinocamax quadratus*, for *Cardiaster pillula*, the gibbous form of *Echinocorys*, and bryozoa occur. A well-marked band of *Echinocorys* occurs in this pit. At a slightly lower level, a pit on the western face is full of conspicuously pyramidate forms of *Echinocorys*. This is evidently near the top of the *Marsupites*-Zone, which clearly runs beneath the summit of the hill near the 200-foot contour on either side, and crosses it towards the north above Denton. Following this band along the western slope of the ridge, and gradually descending in level with the dip of the strata, we come to a small exposure below Rookery Hill, near the house marked 'Foxholes' on the 6-inch Ordnance map. Here plates of *Marsupites* occur at about the 50-foot contour, and confirm the position of this zone on Mount Pleasant.

Having now secured three separate localities in this area, where the position of the *Marsupites*-Zone is accurately known, the theoretical outcrop can be mapped by the usual graphic method upon a contoured map. By this means the probable position of this zone around Bishopstone village and Norton is at once indicated, and the probable strike and dip of the beds are thus found. It remains only to confirm this mapping by further observation in the field. There are several small exposures near Bishopstone village, which thus fall into the zone of *Actinocamax quadratus* near the base of that horizon. This conclusion is confirmed by the abundant occurrence of *Cardiaster pillula*, *Rhynchonella plicatilis*, and gibbous forms of *Echinocorys scutatus*.[1] A further confirmation is afforded by the fact that the 200-foot strike-line on the graphic diagram, continued eastwards, skirts the ridge of Cradle Hill, and cuts Hindover close to the level where numerous *Marsupites*-plates were found.

It is thus proved that in this area the beds are dipping uniformly at an angle of 1 in 30, or about 2° towards the south-west, and that they are not here affected either by faults or by flexures of appreciable magnitude. The *Marsupites*-Zone at Foxholes cottage dips below the alluvium, and is not seen again east of the Ouse Valley. On the west, however, it was found by Dr. Rowe, emerging from beneath the cliff between Old Nore Point and Friar's Bay. The general contour of the country above described is shown in the accompanying diagrams (figs. 2 & 3, p. 448). It remains now to link up this evidence with that furnished by the known exposure in Seaford Cliff. Between Hindover and Seaford Head, along the western slope of the Cuckmere Valley, there are very few exposures of any

[1] I have since found direct evidence of the *Marsupites*-Zone in the valley east of Bishopstone, where a small cutting near the barn yielded brachial ossicles of *Marsupites* or *Uintacrinus* (from its position probably the former).

Fig. 2.—*Section from Denton to Bishopstone.*

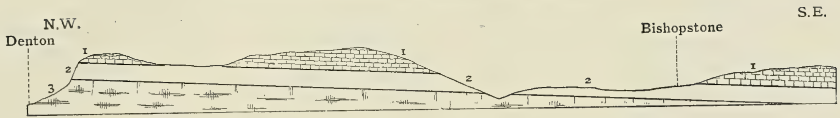
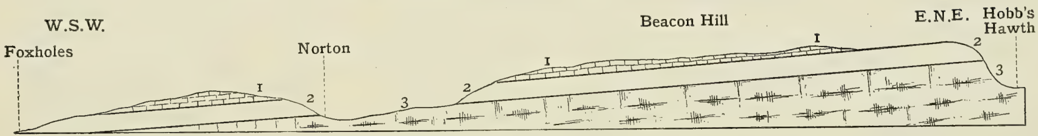


Fig. 3.—*Section from Hobb's Hawth to the Ouse Valley at Foxholes.*



[Scales: horizontal = 3 inches to the mile; vertical = 4 times the horizontal.]

1 = Zone of *Actinocamax quadratus*. 2 = Zone of *Marsupites testudinarius*. 3 = Zone of *Micraster cor-anguinum*.

kind, except near the base, where the zone of *Micraster cor-anguinum* is indicated. Near Exceat Bridge there is a small disused quarry, much obscured by talus, and very barren in fossils. Those found here prove, however, that this quarry is below the level of the *Marsupites*-Zone, as indeed would be expected by its position, less than 50 feet above the level of the river. Proceeding next to the known outcrop of the *Marsupites*-Zone on Seaford Head, the junction with the zone of *Actinocamax quadratus* can be traced eastwards from the Roman Camp to the south of Chyngton Barn, where a small pit yields *Cardiaster pillula* in abundance and other fossils characteristic of the *Actinocamax-quadratus* Zone. The strike of the beds here, therefore, is nearly east and west. At Chyngton Farm, a low hill about 150 feet above the river is capped by an Eocene outlier, which is well exposed in a small opening. It may consequently be inferred that we have here the full thickness of the zone of *Actinocamax quadratus*, which is found to be 150 feet on the east of Seaford Head.[1] The level of the *Marsupites*-Zone here, therefore, must sink below the alluvium of the Cuckmere; and there is consequently a steep dip from the top of Seaford Head, northwards, at an angle of 15° or 20°. There is, in fact, between Seaford Head and Hindover a sharp bend, and a true synclinal valley with dip-slopes in opposite directions, as shown in the diagram (fig. 4, p. 450), the full significance of which will be explained below.

In tracing these outcrops I have tried to avoid loading the description with detailed lists of fossils. It will, however, be useful, before concluding this portion of the subject, to call attention to a few points regarding the fossils collected from this area. In the first place, I must again acknowledge the great value of Dr. Rowe's pioneer work, which I found to be not only a perfectly trustworthy guide in the field, but also remarkably easy for even a novice to assimilate and apply. In one point alone, as previously stated, do the inland exposures appear to me to be in some disagreement with the evidence in the cliff-section. I refer to the band of *Conulus albogalerus*, found near the junction of the zones of *Marsupites testudinarius* and *Micraster cor-anguinum*. Dr. Rowe states that the large pyramidate form of *Conulus* is rare in the cliff-section, and that no band of this fossil exists at this horizon in the Sussex cliffs, although this band is usually found in Thanet and elsewhere. I found, on the contrary, fairly numerous examples of this species wherever there are good inland exposures of the top of the zone of *Micraster cor-anguinum*. This is the case at Friston, at Hindover (in two localities), and at Denton, in each of which localities the presence of this fossil is very marked. I

[1] The possibility of some pre-Tertiary erosion must of course be admitted, but of this there is no evidence, and it seems to be not unreasonable to conclude that the thickness of the *Actinocamax-quadratus* Zone at Chyngton is as great as it is at Seaford, which is only a mile away to the west.

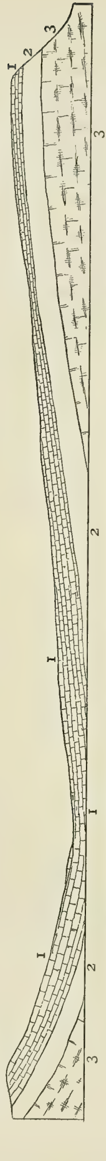


Fig. 4.—*Section from Seaford Head to Hindover.* (*Scales: horizontal* = 3 *inches to the mile; vertical* = 4 *times the horizontal.*)

1 = Zone of *Actinocamax quadratus.* 2 = Zone of *Marsupites testudinarius.* 3 = Zone of *Micraster cor-anguinum.*

noticed also that collections of fossils gathered by a farmer at Hindover, and by a resident at Denton, contained nearly as many examples of the large form of *Conulus* as of *Echinocorys* and *Micraster*. The small rounded shape-variation, which Dr. Rowe calls *conica*, I found, although sparingly, in the zone of *Marsupites*, as he states.

The shape-variations of *Echinocorys scutatus* proved exceedingly useful, except where crushing had destroyed the value of this index. I found two specimens of the large ovate form of this fossil in a band of *Cardiaster pillula,* near the base of the zone of *Actinocamax quadratus*, on Seaford Head. I also procured a specimen of the dwarf pyramidal form of *Echinocorys* in the zone of *Actinocamax quadratus* at Rookery Hill, Bishopstone, where it occurred some 20 feet or so above the base, of which Dr. Rowe says it is very characteristic. *Micraster cor-anguinum* occurs well above the base of the zone of *Actinocamax quadratus* at Hindover, where I found several specimens, at the same level as *Cardiaster pillula.* These were of the usual thin-tested type, and I was only able to extract them in a fragmentary state. *Epiaster gibbus,* not at all a common fossil in Sussex, I found in two localities: one near the top of the zone of *Micraster cor-anguinum* at Denton, and the other well up in the *Marsupites*-Zone at Seaford Head.

I must also record a single imperfect specimen of a belemnite resembling *Actinocamax verus,* in the zone of *Actinocamax quadratus,* in the base of the chalk-pit near Seaford Cemetery. Dr. Rowe, who has seen this specimen, thinks that it is more like *Actinocamax verus* than anything else, especially the inflated form from the zone of *Micraster cor-anguinum.*

From the scarcity of *Cardiaster pillula* in this quarry and the decidedly gibbous form of *Echinocorys scutatus,* which occurs in a band about 10 feet from the base, it is judged that the pit is considerably above the base of the zone of *Actinocamax quadratus.* It is noteworthy, however, that *Actinocamax verus* has not before been found in the *A.-quadratus* Chalk of the South of England.

With regard to *Bourgueticrinus*, I found nipple-shaped heads in the *Marsupites*-Zone, and dumb-bell shaped ossicles in the zone of *Actinocamax quadratus*; but with me these were apparently rare occurrences. Barrel-shaped ossicles at the top of the zone of *Micraster cor-anguinum* seemed to be by far more common.

I attach no importance to my negative results, because my object was rather to map the outcrops than to make long lists of fossils. The exposures, too, are far too poor to enable such lists to be easily secured.

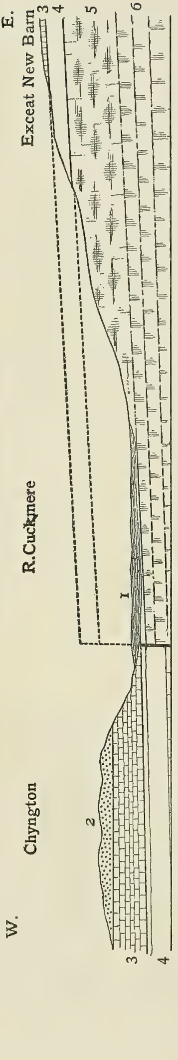
III. Structural Features.

It is now possible to consider the structural features of the Chalk in this area. In the country north and west of Seaford, between the Cuckmere and the Ouse, it has been shown that the beds dip gently towards the south-west, at an angle of 2°, with no sign of any appreciable flexure. At Hindover, the top of the *Marsupites*-Zone is at an altitude of about 225 feet above O.D., whence it sinks gradually towards the south until, near Chyngton, it lies below the level of the alluvium of the Cuckmere, to rise again along the slope of Seaford Head to a height of 287 feet O.D. Thus, while there is a gentle southerly dip-slope from Hindover to Chyngton, there is a steep northerly dip-slope from the latter place to the top of Seaford Head. The strike of the beds at Seaford Head has been shown to be nearly east and west. Evidently, therefore, Seaford Head has been carved out of the limb of a sharp flexure, with its steep face towards the north. This fold, only a fragment of which remains, apparently resembles in form the uniclinal fold of the Isle of Wight, and, as in that case, appears to have been caused by a thrust from the south. It is this flexure which brings up the zone of *Micraster cor-testudinarium* along the base of the cliff between Cuckmere Haven and Seaford Head, in the fine coast-section described by Dr. Rowe.

On the opposite side of the narrow Cuckmere Valley, however, not a trace of this flexure exists. As has been shown above, the beds are there nearly horizontal, with a very slight general inclination towards the south-west. This same feature can be seen also in the flint-bands in the *Micraster cor-anguinum*-Zone along the eastern side of the Cuckmere Valley. The uniclinal fold of Seaford Head, therefore, comes to a sudden termination somewhere in the Cuckmere Valley. A difference in level of nearly 300 feet occurs between the nearly flat *Marsupites*-Zone on the plateau east of the Cuckmere, and the same bed at the bottom of the trough beneath Chyngton. Only two interpretations of this fact seem possible: either the fold dies out, or there is a fault in the Cuckmere Valley.

I discard the first supposition because the distance is too short, and whatever westerly pitch the fold may have it is too small to

Fig. 5.—*Section from Chyngton to Exceat New Barn. (Scales: horizontal = 3 inches to the mile; vertical = 4 times the horizontal.)*



1 = Alluvium of the Cuckmere. | 3 = Zone of *Actinocamax quadratus.* | 5 = Zone of *Micraster cor-anguinum.*
2 = Tertiary (Woolwich & Reading Series. | 4 = Zone of *Marsupites testudinarius.* | 6 = Zone of *Micraster cor-testudinarium.*

warrant such a conclusion.[1] The flexure at Chyngton is too deep and too sharp to enable it to die out completely, within a distance which can scarcely exceed a quarter of a mile. Such an interpretation would involve the formation of a cul de sac, which would, I think, be a geological anomaly. It would, in fact, require as steep and sudden a rise to the east as the existing rise to the south.

I am disposed, therefore, to favour the second conclusion, that there is a transverse (north-and-south) fault in the Cuckmere Valley (fig. 5). I adopt this view because it seems to be more simple than the other alternative. At the same time, it should be understood that the existence of this fault can only be proved by inference, and I must admit the possibility of the less simple explanation being correct. Such faults are not unknown in connexion with the folded Chalk strata of the South Coast. Dr. Strahan has described them in connexion with the Purbeck flexure,[2] and Dr. Rowe noticed them in the cliff at Friar's Bay, west of Newhaven.[3] The interesting fact in the case of the presumed Cuckmere fault, however,

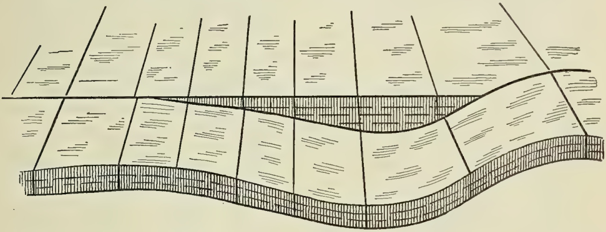
[1] The pitch of the fold between Chyngton and Seaford is less than 1°. This is inferred from the difference in level of the base of the Tertiary beds between these points. The same conclusion is drawn from the approximate horizontality of the zone of *Micraster cor-testudinarium* in the cliff-section between Cuckmere Haven and Seaford Head.

[2] 'Guide to the Geological Model of the Isle of Purbeck' Mem. Geol. Surv. 1906, p. 7.

[3] Proc. Geol. Assoc. vol. xvi (1899–1900) p. 337.

is, that while the beds have been transversely folded on one side of the fault-line, they remain normal on the other side. I have represented this feature in the accompanying diagram (fig. 6). We may have here, therefore, an example of a fault with a variable throw, such as is described by Green in his well-known text-book,[1] without reference, however, to an actual example; nor can I recall any description of a similar fault, although such doubtless exist.

Fig. 6.—*Diagram illustrating the fault in the Cuckmere Valley.*



The variability of the throw of this fault would explain why its presence is not more in evidence in the cliff-section, and Mr. C. Davies Sherborn's rendering of the appearance of the strata in the cliff is in no way invalidated by this hypothesis, although it gives a false impression of a north-and-south undulation instead of the east-and-west flexure now shown to exist.[2]

In order to understand the full significance of the Seaford flexure, it will be well to consider next what place it occupies in the general system of folds comprehended in the Wealden uplift; for which purpose I have indicated on a map the locality and strike of the more important flexures, especially those at present known on the south of the main anticlinal axis (fig. 7, p. 454). They have been aptly described as ripples on the wave of general upheaval to which the Wealden anticline is due. Details respecting these have been so fully described by Topley,[3] Dr. Strahan,[4] and Mr. Clement Reid[5] that they need not be repeated here. Many of them are quite minor flexures, and from my own experience in the Wealden area, they are often merely gentle symmetrical folds,

[1] 'Physical Geology' 2nd ed. (1883) p. 368.

[2] See pl. ix, Proc. Geol. Assoc. vol. xvi (1900). It should be remembered that the line of this section is not straight, as the coast-line deviates northwards below Seaford Head. It is this deviation alone which exposes the apparent westerly dip of the beds.

[3] 'Geology of the Weald' Mem. Geol. Surv. 1875, pp. 277, 278.

[4] 'Geology of the Isle of Wight' 2nd ed. (1889) p. 239; also 'Guide to the Geological Model of the Isle of Purbeck' Mem. Geol. Surv. 1906, p. 5.

[5] 'Geology of the Country near Chichester' Mem. Geol. Surv. 1903 (Expl. of Sheet 317) p. 2.

unlike the sharp uniclinal extending from Purbeck through the Isle of Wight, and now shown to exist at Seaford Head. Even the Greenhurst anticline, a considerable fold extending for several miles, is quite a symmetrical undulation. It seems to be clear, therefore, that the Seaford fold belongs to the Purbeck—Isle of Wight system, which, as is known, consists of a series of uniclinal flexures arranged in échelon, each with a steep face towards the north.

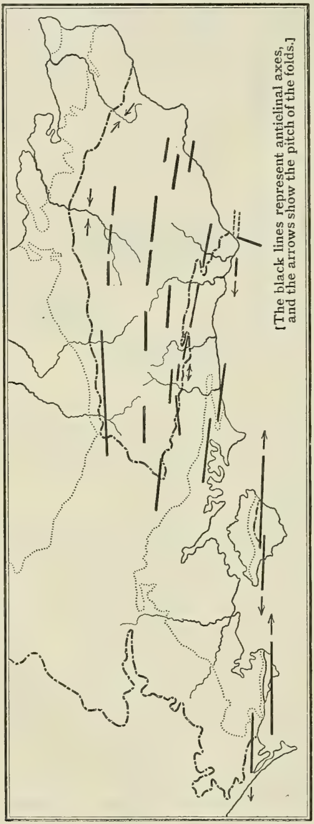


Fig. 7.—Map showing the lines of flexure in the South-East of England.

[The black lines represent anticlinal axes, and the arrows show the pitch of the folds.]

It is possible also to suggest a reason why the Seaford fold should come to a sudden termination in a fault in the Cuckmere Valley. Mr. Clement Reid has shown that at Eastbourne there is a strong transverse fold, running north-eastwards below Beachy Head,[1] with a steep westerly face, and affecting the strike of the beds in this locality.[2] This implies an easterly thrust which would tend to counteract and neutralize the southerly thrust to which the Purbeck—Isle of Wight folds were due. The complex strain thus set up may have found relief in the production of the Cuckmere Fault.

[1] 'Geology of the Country around Eastbourne' Mem. Geol. Surv. 1898 (Expl. of Sheet 334) p. 11.

[2] Topley erroneously interpreted this somewhat complicated structure as two folds parallel to the main Wealden axis. One of these, the Holywell syncline, he thought might possibly be continued through Seaford to Newhaven. See 'Geology of the Weald' Mem. Geol. Surv. 1875, p. 229.

If this was so, we may regard the Cuckmere Fault as the true geographical termination of the Hampshire Basin. This view is supported by certain physiographical features of this area, to which I will now call attention.

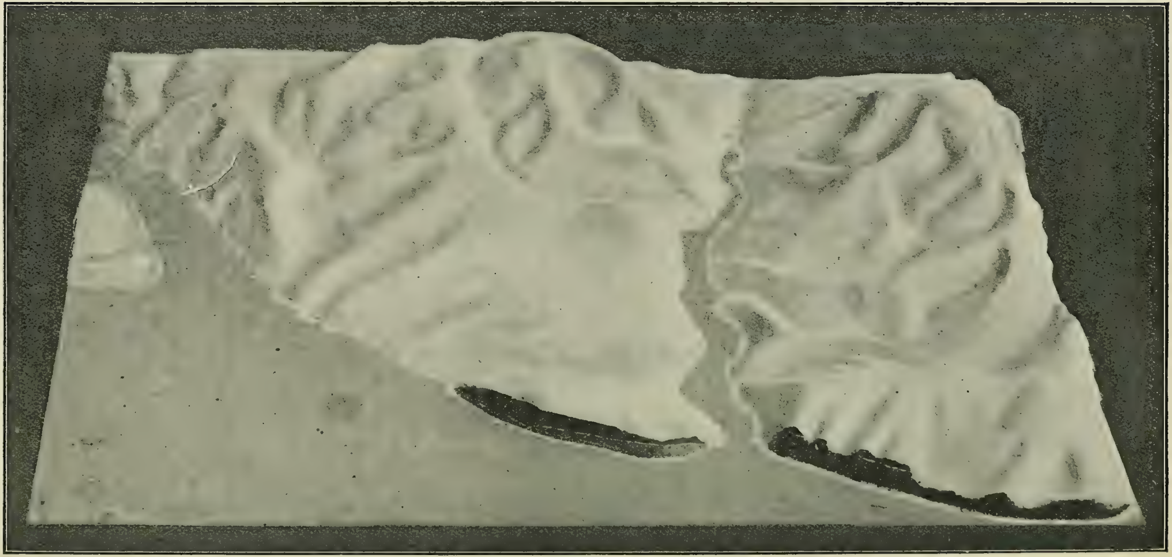
IV. Physiography.

A glance at the relief-diagram (fig. 8, p. 456) shows a striking difference in the river-mouths of the Ouse and the Cuckmere. That of the Ouse is wide, and is bordered on the east towards Seaford by low ground, while the Cuckmere reaches the sea through a narrow gorge, flanked on each side by high cliffs. The line of water-parting between these rivers runs nearly due south from Firle Beacon until it reaches the ridge above Hobb's Hawth, where it turns sharply to the east, following the top of this ridge along Cradle Hill to Hindover. From this point it runs southwards, approximately parallel with the Cuckmere, to Chyngton and Seaford Head: along this latter portion of its route it is less than a mile from the river. We have seen that it is here that occur the two counter dip-slopes, caused by the Chyngton syncline. By this movement a large part of what might otherwise have been the Cuckmere drainage-area has been diverted into that of the Ouse. Possibly a slight westerly pitch of the synclinal axis has facilitated this result. It would have been expected that the Cuckmere would thus have been diverted into the Ouse, becoming a tributary of that river rather than performing the apparently difficult task of penetrating the ridge connecting Seaford Head with the Friston plateau. This latter course may perhaps have been made possible by the presumed line of fault, a suggestion which is supported by the marked eastward deflection of the river where it penetrates this ridge. I do not, however, imagine that this fault-line, if it exists, had anything to do with the general course of the river-valley across the Chalk escarpment. Topley has offered strong arguments in favour of the view that the course of Wealden rivers was mainly determined by slight transverse undulations.[1] There is some indication that this may have been so in several cases, although there is not only no evidence of any rise in the beds between the Cuckmere and the Ouse, but rather, as has been shown above, there is a strong proof that the beds in this area are not folded transversely. How far the Eastbourne transverse fold may have influenced the course of the Cuckmere is not easy to determine. Leaving aside the question of the general direction of the Cuckmere Valley, however, it seems to be clear that the Seaford Head movement has curtailed the drainage-area of this river, and has determined the present position and shape of its mouth.

The next point to which I will refer is the very marked contrast between the surface-features on the east and those on the west side

[1] 'Geology of the Weald' Mem. Geol. Surv. 1875, pp. 276–78.

Fig. 8.—*Model illustrating the physiography of the Seaford district.*



of the lower part of the Cuckmere Valley: this is well brought out in the relief-diagram (fig. 8). The east side is deeply intersected by dry valleys; while the west side is but a faintly eroded dip-slope, except near Bishopstone, where we pass beyond the limits of the depression. This feature may, therefore, also be attributed to the influence of the Seaford Head fold. The depression formed by this fold would retain its Tertiary cover long after it had been denuded from the adjoining areas. Within the limits of this basin extensive spreads of Eocene strata are still preserved: the Newhaven Tertiary beds, and those at Seaford and Chyngton, are remnants owing their preservation to this hollow. That at Chyngton is particularly instructive, because it lies partly in the Cuckmere Valley itself: a position which it would scarcely have occupied, if this locality had not been situated at the bottom of the trough. There are also other remnants of Tertiary beds in this area which are not marked on the maps of the Geological Survey. Some of these occupy deep pipes in the Chalk, one of which is situated close to the northern boundary of the *Actinocamax-quadratus* Chalk, near the 300-foot contour, about 2 miles due north of Seaford, where it has been excavated to a depth of 20 feet for sand for the new golf-links. That this pipe is in *A.-q.* Chalk is proved by direct fossil evidence, and curiously I obtained here a perfect specimen of *Cardiaster pillula* from the Tertiary sand itself. I have found no evidence of any transgression in the Tertiary beds beyond the limits of the *Actinocamax-quadratus* Zone.[1] It seems to me clearly established that the persistence of the Eocene cover over the area of the synclinal depression accounts for the absence of deep dry valleys from the west side of the Cuckmere Fault, and their recurrence beyond the limits of the hollow.

A further result following from the geological structure of this area is the break in the continuity of the cliff between Seaford Head and Newhaven. This is clearly due to the fact that the coast-line here intersects the trough of the basin. Seaford Head is the last remnant of a limb of the uniclinal fold, the trend of which is lost westwards in the Channel. The Newhaven cliffs are on the northern margin of the basin, and the apparent horizontality of the beds there is due to the fact that the cliff approximately follows the direction of the strike. Towards Brighton the cliff trends still more northwards, and thus recedes farther from the trough of the fold, which may explain the absence of Tertiary beds for some distance west of the Newhaven outliers.

The view here expressed with regard to the absence of deep valleys around Seaford is based on the theory that such valleys are due mainly to erosion. The origin of such valleys in Chalk districts has recently been much discussed, although data for studying their relationship to the local stratigraphy have not generally been available.

[1] The numerous greywethers about Alfriston have probably been let down into their present position by the removal of the Chalk.

The relief-model illustrating this paper brings out very clearly certain points not so readily realized, either from a study of the ground, or from an examination of contoured maps, owing to the difficulty in each case of taking a comprehensive view of a sufficiently large area.

The first point to be noticed is the marked symmetry of these depressions. Starting at the water-partings as dip-valleys, they gradually wind round into strike-valleys, which direction is maintained until they debouch into the main river-valley. This would be expected to be the normal course of tributary valleys formed by surface-drainage. Another striking feature is their symmetrical transverse outline. Each one presents a gradual slope in the direction of the dip, followed by a steep rise in the opposite direction. This is also characteristic of valleys of surface-erosion. It has lately been suggested that such valleys in Chalk areas are solution-subsidences along the course of master-joints in the Chalk,[1] and it is true that the Chalk in this area does occasionally show prominent dip and strike-joints. Thus the slips on the steep face of Hindover often follow a marked zigzag course, following in turn each of these sets of joint-planes, while in Denton Chalkpit pronounced vertical dip-joints are visible. The stratigraphy of the beds, however, at once disproves the theory of a sagging of the strata along the course of swallow-holes following joint-planes in the Chalk; for, if this had been the case, the outcrops would show no relation to the surface-contours. I have carefully examined the stratigraphical features of all the valleys intersecting the Chalk in this area within the limits of the three upper zones, and there is clear evidence that no such surface-subsidence has taken place. The successive outcrops invariably maintain their correct relations to the surface-contours.

The same conclusion is confirmed by the fact that the dry valleys have been swept remarkably free from superficial deposits. There are terrace-gravels along the rivers, and there are remnants of high-level gravels, and débris of Tertiary beds on the high ground; but, with the exception of a thin rainwash, the valleys themselves are free from these deposits. At Friston, for example, there is a deposit of 10 feet of coarse gravel at an altitude of 350 feet, which is sharply truncated by the Jevington dry valley. On the hill above Hobb's Hawth, there is a similar sudden termination to the thick covering of débris overlying the zone of *Actinocamax quadratus*, as soon as the Hobb's Hawth valley is entered. The solution-theory would require that such insoluble deposits should, above all others, be let down into these valleys in their full thickness.

Both from the symmetry and from the stratigraphy of these valleys, therefore, they must be regarded as true valleys of erosion. Mr. Clement Reid's ingenious theory of their origin,[2] to which I

[1] Rev. E. C. Spicer, Quart. Journ. Geol. Soc. vol. lxiv (1908) pp. 335–42.
[2] Quart. Journ. Geol. Soc. vol. xliii (1887) p. 364.

need not here refer in detail, seems to be a very possible explanation of their present depth. At the same time, it is not unlikely that the solubility of the Chalk has assisted its removal, and that joints may have played some part in promoting slips and maintaining the slope of their steeper faces.[1]

There is one feature of these dry valleys which does not appear to be easily explained. I allude to their narrow junctions with the main valley in which the river flows. All the dry valleys in this area become very constricted at their lower extremities. I do not attempt to offer an explanation of this peculiarity, although it must be looked upon as possessing some significance with regard to their mode of origin.

In conclusion, I would say that I have endeavoured in this paper to illustrate the application to field-geology of the zonal method of studying Chalk areas. The district selected is small, but it is interesting as throwing some light upon the geological and physiographical features of what may be regarded as the eastern extremity of the Hampshire Basin. I think that there can be no doubt that the Seaford Head flexure is of the same age as that of the Isle of Wight, which is certainly post-Oligocene, and probably pre-Pliocene in date. If, therefore, the Seaford Head flexure is actually part of the Purbeck—Isle of Wight system, we have here the precise southern boundary of this end of the Hampshire Basin, which, as has been shown above, terminates abruptly eastwards in the Cuckmere Valley.

Discussion.

Mr. G. W. Young welcomed the Author as an accession to the group of Chalk enthusiasts, and congratulated him on the interest of his first communication on the subject. He was quite prepared to accept the Author's view as to the suggested fault in the Cuckmere Valley, as the abrupt change in the direction of the strike of the Chalk and the overthrusting seen in the neighbourhood of Eastbourne rendered it probable that considerable earth-movements had taken place in the surrounding districts. The little low-lying Tertiary outlier at Chyngton Farm gave the clue to the whole situation.

The Author's belief that the Seaford uplift was an eastward prolongation of the Isle-of-Wight ridge was interesting, especially in regard to Mr. Clement Reid's suggestion, some years ago, that Beachy Head marked the eastward termination of that movement; but the speaker preferred the more generally accepted theory that

[1] On this point see A. J. Jukes-Browne, Geol. Mag. dec. 5, vol. v (1908) pp. 529–34.

the escarpment of the South Downs was once united with that of the Boulonnais, and not with that of the Isle of Wight.

The relief-model exhibited showed well how the remarkably horizontal appearance of the *Micraster cor-testudinarium*-Zone between Seaford Head and the Cuckmere was accounted for by the coast-line being coincident with the strike of the beds. It was probable, however, that the dip of the lower beds was not so great as that of the upper beds as in the Isle of Wight, for otherwise the inward dip would have been betrayed in the indentations of the cliffs.

He was not quite in accord with the Author as to the origin of the dry Chalk valleys, but time would not allow of discussion of that part of the paper.

Mr. O. T. Jones wished to ask the Author whether he had considered an alternative explanation of the relations of the fold and the fault which he described. The speaker suggested that the fault might be later than the uniclinal fold, and that the flat-lying beds on the east of the fault might correspond to a part of the fold-structure lying north or south of the trough, and where therefore the beds would be nearly horizontal. The state of affairs described by the Author might have been brought about by a horizontal movement along the fault, which shifted the axis of the fold northwards or southwards and brought the flat-lying beds against the centre of the trough.

The Rev. E. C. Spicer pointed out that the Chalk area of the district had strongly marked surface-features, while the adjacent Tertiary area had low relief. It was difficult to realize how any denuding agency could produce such markedly different results in the same area by mechanical erosion at the surface. If the Chalk area is being modified by solution-activity, these morphological differences could be more easily understood.

Dr. J. W. Evans thought, with reference to a previous speaker's suggestion, that it was more natural to suppose that the folding on the west side of the fault was part of the same movement as that which caused the fault, than that the fold was first formed and subsequently dislocated. Dip-faults were, in fact, usually the outcome of the difference in flexuring on the two sides of a fracture ('Economic Geology' vol. ii, 1907, p. 805).

The Author said that, although the *Marsupites*-Chalk possessed distinct lithological characteristics, these were not sufficiently definite to enable boundary-lines to be drawn with certainty by that means alone. As to the precision with which these lines could be fixed in the field, in this area the zonal limits were very sharply defined. Below the lowest *Cardiaster-pillula* Band, which was taken as the base of the *Actinocamax-quadratus* Zone, were 20 feet of easily recognizable passage-beds before the top of the *Marsupites*-Band (about 50 feet thick) was reached. Then came the *Uintacrinus*-Band (about 30 feet thick), below which a *Conulus*-

Band marked the top of the *Micraster cor-anguinum*-Zone. These bands were easily to be identified, and horizons could often be fixed within a few feet, even in shallow exposures.

With regard to the interpretation of the fault suggested by Mr. O. T. Jones, this involved considerable lateral movement, and the Author considered it to be a less simple explanation than his own. Moreover, it implied a continuation of the fold, of which he found no evidence, somewhere on the east side of the river.

He would not, at that late hour, refer to other points suggested in the discussion, and he thanked the Fellows for their kind reception of his paper.

27. *The* Pitting *of* Flint-Surfaces.

By Cecil Carus-Wilson, F.R.S.E., F.G.S. (Read May 26th, 1909.)

[Abstract.]

Regular pittings of uniform size are occasionally seen on flints which have been exposed to the weather. They have been referred to by various authors, but no satisfactory explanation of their origin has been given. The Author procured some interesting examples occurring in a recent deposit near Folkestone. This deposit is formed of materials which appear to have been washed down from the adjacent Chalk hills. The flints appear to have been derived from the sandpipes in the Chalk: their surfaces are much decomposed. The removal of the colloid silica has rendered them very porous, and they absorb a good deal of water. It is believed that the pittings are due to mechanical action. Observations and experiments carried out by the Author indicate that such markings cannot have been produced by blows, nor by any process of desiccation, and that the freezing of the absorbed water seems to be the only satisfactory explanation to account for the various details of the phenomenon.

28. *A* New Species *of* *Sthenurus*.

By Ludwig Glauert, F.G.S. (Read June 16th, 1909.)

[Abstract.]

In a large collection of remains of extinct Marsupial mammals from the Mammoth Cave, Margaret River (Western Australia), the Author recognized several mandibles of a new kangaroo of the genus *Sthenurus*. He now communicates a detailed description of one specimen, and shows that the new species most nearly resembles *Sthenurus oreas* (De Vis) and *Sth. atlas* (Owen).

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C. A. White

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Session 1909–1910.

1910.

Wednesday,	January	12*—26*
,,	February (Anniversary, Friday, Feb. 18th)	9*—23*
,,	March	9*—23
,,	April	13*—27
,,	May	11*—25
,,	June	15*

[*Business will commence at Eight o'Clock precisely.*]

The dates marked with an asterisk are those on which the Council will meet.

29. *The* Hartfell-Valentian Succession *in the* District *around* Plynlimon *and* Pont Erwyd (North Cardiganshire). By Owen Thomas Jones, M.A., B.Sc., F.G.S. (Read May 12th, 1909.)

[Plates XXIV & XXV—Maps.]

Contents.

I. Introduction.

The area described in this paper forms part of the hilly country some 12 to 16 miles to the east of Aberystwyth. It extends for a distance of about 9 miles, from the Plynlimon Mountains near the northern margin, to the Ystwyth Valley which forms the southern boundary; the eastern limit lies on the elevated tract which forms the divide between the coastal drainage and that of the River Wye and its tributaries, while its western margin is roughly defined by the western slope of the Rheidol Valley.

The area of 40 square miles or so included within these boundaries is given over almost entirely to sheep-grazing, and only small tracts along some of the valleys are under cultivation. In former times mining operations were vigorously carried on, but that industry is now decadent.

The small village of Pont Erwyd stands in the Rheidol Valley near the western margin of the district, and on the main road from Aberystwyth to Llanidloes which divides the area into two almost equal portions.

Regarded broadly, the district forms part of the elevated 'plateau' which is characteristic of so much of Central Wales; south of the Aberystwyth road it reaches a nearly uniform level of about 1900 feet, but north of the road it rises gradually to 2468 feet on Pen Plynlimon Fawr—the culminating point of the plateau. The numerous valleys which intersect the tract are deep, steep-sided, and characteristically devoid of trees, which are almost confined to the gorge-like valleys of the Rheidol and the Ystwyth. This general absence of trees and also, over large areas, of gorse

and heather, gives to the country a decidedly monotonous aspect, which is but little liable to seasonal variation.

At first sight, this monotony seems to extend to the rocks, for in a hurried traverse, especially across the higher ground, one might readily believe that the country for mile after mile contained nothing but an interminable series of pale greenish shales and mudstones of so forbidding an appearance that it was out of the question to look for fossils. It is only by working carefully along the numerous sections that the great variety of the rocks and their exceptionally fossiliferous nature is appreciated; and it is only then that the geological structure becomes revealed in the disposition of the surface-features, which seem at first to defy any attempt at a simple explanation.

II. Historical Review.

The general features of the region of Central Wales were ably described by Dr. Herbert Lapworth (6)[1] in a paper read before the Geological Society in 1900, wherein he showed how a certain amount of order had been gradually evolved out of the chaotic mass of slates, grits, and conglomerates which covers an area of something like 1800 square miles. It is unnecessary for me to go over the ground there dealt with, and I shall therefore confine myself to the literature which bears closely on the district described in this paper. The list on p. 467 includes all the references that I have been able to find.

I am not aware that Murchison ever visited this part of Wales, which was not coloured on the map accompanying the 'Silurian System'; the rocks were believed by him to belong to the Cambrian country of Sedgwick.

We owe to Sedgwick (1) the first attempt at a classification of the rocks. He made 'hasty traverses' across the district on two occasions—1832 and 1846,—and as a result he inferred the rocks to be below the 'Upper Silurian,' for he says:—

'I believe the true demarcation of the Upper Silurian rocks [base of Wenlock] passes in an irregular line from the neighbourhood of Mallwyd to the hills near Llanidloes, leaving the Plynlimmon ridges far to the west.' (P. 151.)

With regard to their inferior limit, he remarks:—

'these groups . . . . are superior to the slates and porphyries of the whole Cader Idris range and I think also superior to the Bala Limestone.' (P. 155.)

He divides the rocks within these limits into four principal groups [p. 151], namely: (1) the Aberystwyth Group; (2) the Plynlimmon Group; (3) the Upper South Welsh Slate Group[2]; and (4) the Cambro-Silurian Group. He apparently regarded them

[1] These numerals in parentheses refer to the List of the Literature at the end of this section, p. 467.

[2] On p. 153 of the paper Sedgwick denotes Group (3) 'The Rhayader Slates.'

as being arranged in ascending order from west to east or from north-west to south-east, but he admits that the actual order of superposition is obscure. He included in the 'Plynlimmon Group' most of the rocks to the east of the Aberystwyth Group, as far as Llangurig.

It is now known that, although Sedgwick's groups are not mutually exclusive, and the order of superposition is not what he believed it to be, yet the limits of age assigned to the groups collectively are remarkably near the truth.

About this time the area was being examined by the officers of the Geological Survey, and the maps were published between 1848 and 1850. A horizontal section across the southern portion of the district was issued about 1845. The mineral veins were examined by Warington W. Smyth, and the results were published in 1848 (2). From certain letters which Sir Andrew Ramsay wrote to Aveline in 1856, it appears that he regarded the grit-groups of Aberystwyth, Cwm Ystwyth, and Plynlimon as one and the same group, which he tentatively placed at about the level of the Lower *Pentamerus*-Sandstones [= Lower Llandovery] or the sandstones of the Cefn-y-Gamrhiw ridge near Rhayader [? = Upper Bala and Lower Llandovery]. A few months later, Aveline seems to have seen reason for raising the Aberystwyth Grits to a higher level.

In 1866 the official memoir on North Wales, compiled by Ramsay (3), appeared. On the map accompanying it the letter *b* 4 (indicating Lower Llandovery age) is sprinkled over a large part of Central Wales, especially on the grit-outcrops such as those of Plynlimon, Aberystwyth, and Cwm Ystwyth.

In 1869 Mr. Hopkinson (4) recorded the following species of graptolites from Aberystwyth:—*Monograptus priodon*, *M. Hisingeri*, *M. Sedgwicki* var., and gave a figure of the last-named. He assigned the rocks to the Caradoc age, in accordance with the then current views on the geological horizon of these species. The value of the graptolite as an index of age had not at that time been discovered; and even when, several years later, its use had been recognized, the significance of Mr. Hopkinson's find was not realized, else from the presence of *Monograptus priodon* the Gala or Tarannon age of these rocks would have been suspected.

In 1872 W. S. Symonds in his 'Records of the Rocks' refers to the rocks of Plynlimon and of Devil's Bridge as of Lower Llandovery age, and mentions *Atrypa* [now *Meristina*] *crassa* as having been found at the latter place.

The first systematic attempt to reduce the rocks of this district into order was made by Walter Keeping (5), who communicated his results to the Geological Society in 1881. He established three groups in ascending order: (1) the Aberystwyth Grits; (2) the Metalliferous Slate Group; and (3) the Plynlimon Grits. Groups 1 & 2 he united under the name of Cardiganshire Group; groups 2 & 3 constituted the Plynlimon Group of Sedgwick.

He followed his predecessors in regarding the grits of Plynlimon

and Cwm Ystwyth as the same, but placed the Aberystwyth Grits far below them. His most important achievement was the discovery of graptolites in several places, from which he was able to infer that the beds were on the whole of Upper Birkhill age :—

'From the fossil evidence, therefore, there can be no hesitation in referring our Mid-Wales rocks to the same age as the Upper Birkhill of Scotland ; and beyond the occurrence of the three species just mentioned in the rocks of the Devil's Bridge, there is nothing that conveys the slightest hint that any of our strata are newer than Upper Birkhill.' (P. 166.)

In regard to the general structure, he recognized

'four different lines of north-and-south foldings between Aberystwyth and Plynlimmon—namely : (1) the principal [anticlinal] axis of Aberystwyth ; (2) the principal [synclinal] axis of Plynlimmon ; and (3) the two minor axes running (*a*) from Ystrad Meurig through Llantrisant and Cwm Symlog, and (*b*) along the gorge of the Rheidol about Pont Erwyd and the Devil's Bridge.' (Pp. 154–55.)

I shall not attempt to criticize Keeping's work in detail. His paper contains much that is good ; but, from my investigations in the Pont Erwyd district, I have been forced to an entirely different conclusion in regard to the stratigraphical succession. As a fact, Keeping's paper carried a very strong hint that something was wrong, in the form of a palæontological appendix by Prof. Charles Lapworth, to whom a few of the graptolites had been sent for identification. From the evidence before him Prof. Lapworth arranged the beds in the following descending order :—

'D. The *M. turriculatus* beds of the Devil's Bridge.
C. Next below (or perhaps identical with D) the Cefn Hendre grits [part of the Aberystwyth Grit Group].
B. Then comes the rich graptolitic zone of Morben and Cwm Symlog.
A. Lowest of all lie . . . . . the *Diplograpsus* beds of . . . . . Steddfa Gurig.' (P. 167.)

According to this arrangement, the Metalliferous Slates (A & B) are older than the Aberystwyth Grit Group, and the beds A, which are on the supposed synclinal axis of Plynlimon, ought to be, according to Keeping, almost the highest beds in the district.

It is a striking tribute to the value of the graptolite as an index of geological age, and to Prof. Lapworth who first made that value clear, that he was able to establish the order of succession of the strata from an inspection of a few graptolites, and to maintain it in the face of supposed stratigraphical evidence leading to a diametrically opposite conclusion.

Since the appearance of Keeping's paper no one had worked on the district, until I began there in the summer of 1903 ; but when, in 1900, Dr. Herbert Lapworth established his Rhayader succession (6), showing that there at any rate Keeping's interpretation would not hold, doubt was thereby cast on the other districts with which he dealt ; and in 1905, when the Geologists' Association visited Plynlimon, Dr. Lapworth found Gwastaden or Lower Llandovery graptolites near Eisteddfa Gurig (7).

In the Geological Magazine for 1906 (8) I gave a very brief sketch of the succession and of the structure of the area, so far as it had been investigated at that time.

A few species of graptolites from the Pont Erwyd district were figured by Miss Elles & Miss Wood in the Monographs of the Palæontographical Society, vol. lxi, issued for 1907 (9).

Literature.

(1) 1847. A. Sedgwick. 'On the Classification of the Fossiliferous Slates of North Wales, &c.' Quart. Journ. Geol. Soc. vol. iii, p. 133.

(2) 1848. W. W. Smyth. 'On the Mining District of Cardiganshire & Montgomeryshire' Mem. Geol. Surv. vol. ii, pt. 2, p. 655.

(3) 1866. A. C. Ramsay. 'The Geology of North Wales' Mem. Geol. Surv. vol. iii, 1st ed. 2nd ed. 1881.

(4) 1869. J. Hopkinson. 'On British Graptolites' Journ. Quekett Microscop. Club, vol. i (1869) p. 151 & pl. viii, figs. 4 *a*–4 *b*.

(5) 1881. W. Keeping. 'The Geology of Central Wales, with an Appendix by C. Lapworth' Quart. Journ. Geol. Soc. vol. xxxvii, p. 141.

(6) 1900. H. Lapworth. 'The Silurian Sequence of Rhayader' Quart. Journ. Geol. Soc. vol. lvi, p. 67.

(7) 1906. H. Lapworth. 'The Geology of Central Wales' Proc. Geol. Assoc. vol. xix (1905–1906) pp. 160 & 232–33.

(8) 1906. O. T. Jones. 'The Geology of the Plynlimmon District' Geol. Mag. dec. 5, vol. iii, p. 336.

(9) 1907. G. L. Elles & E. M. R. Wood. 'Monograph of British Graptolites,' pt. vi, pp. 258, 264, 265 & text-figs. 181 *a–c*, p. 266 & pl. xxxi, figs. 11 *e*, 12 *b*, *c*, *d*, 14 *b*, *c*.

III. The Stratigraphical Succession.

The great series of shales, mudstones, and grits reaching a thickness of between 7000 and 8000 feet which occurs in the Pont Erwyd district has been divided into three primary divisions or Stages, which have been further divided into Groups; and in most cases it has been possible to recognize, within the latter, minor subdivisions generally characterized by a certain species or assemblage of species of graptolites, when they are termed zones, one of the species being chosen as an index of the zone. Occasionally a still smaller subdivision into subzones or 'bands' has been adopted, which may only apply locally in some cases, but in others can be shown to hold over wide areas outside the district. It has been thought desirable to give local names to the Stages and Groups, and although this tends to the introduction of a considerable number of such names into geological literature, it is considered safer to do so than to correlate the formations directly with those of distant areas, a process which is always liable to some error, and one into which the personal element enters of necessity. The general classification used throughout this paper is, therefore, as follows (in descending order):—

VALENTIAN.	C. Ystwyth Stage.	(c) Rhuddnant Group.	2. Rhuddnant Grits.	
			1. Rhuddnant Shales.	
		(b) Myherin Group.	2. Blaen Myherin Mudstones.	
			1. Dolwen Mudstones.	
		(a) Devil's Bridge Group.	Mudstones with thin grit-bands.	
	B. Pont Erwyd Stage.	(c) Castell Group.	3. Flags and shales. (Zone of *Monograptus sedgwicki*.)	
			2. Shales and mudstones. (Zone of *Cephalograptus cometa*.)	
			1. Mudstones and shales. (Zone of *Monograptus convolutus*.)	
		(b) Rheidol Group.	4. Black shales and mudstones. (Zone of *Monograptus communis*.)	δ. *Leptotheca*-band.
				γ. *Magnus*-band.
				β. *Triangulatus*-band.
				α. *Triangulatus*-var.-band.
			3. Flags and black shales. (Zone of *Monograptus cyphus*, sensu stricto.)	
			2. Flags with thin shales. (Zone of *Monograptus rheidolensis*, sp. nov.)	
			1. Flags and shales. (Zone of *Monograptus atavus*, sp. nov.)	
		(a) Eisteddfa Group.	2. Flags, shales, and grits. (Zone of *Cephalograptus (?) acuminatus*.)	
			1. Flags with thin shales. (Zone of *Glyptograptus persculptus*.)	
HARTFELL.	A. Plynlimon Stage.	(c) Bryn-glâs Group.	Mudstones.	
		(b) Drosgol Group.	Grits, conglomerates, and mudstones.	
		(a) Nant-y-Môch Group.	Flags with thin shales. (Zone of *Dicellograptus anceps*.)	

IV. Detailed Description of the Beds.

A. The Plynlimon Stage.

The Nant-y-Môch Beds (*Aa*) are probably the lowest which are exposed within the limits of the region examined. They crop out with a westerly dip of 36°, in the small stream Maesnant-fach which flows northwards to join a tributary of the Rheidol called Nant-y-Môch near the farm of the same name. As the strike of the beds coincides with the stream-course, only a thickness of 10 to 15 feet is exposed. They consist of blue flags striped with thin greyish-white siliceous seams and dark-blue shaly partings, along some of which fossils were found (F. 1 in the Map, Pl. XXIV). On prolonged weathering they become greyish-white to a depth of an inch or two, while the surfaces and joints are coated with light lemon-coloured or orange stains. The abundance in them of crystallized pyrite is a striking character; the mineral occurs as cubes and dodecahedra, either scattered, or aggregated along certain bedding-planes in bands of an eighth to a quarter of an inch thick. With the exception of one small example of *Remopleurides* and an

undetermined gasteropod, the only fossils obtained were graptolites of the species *Dicellograptus anceps*,[1] *Orthograptus truncatus*, *O.* cf. *mutabilis*, and *Climacograptus scalaris* var. *miserabilis*: these are fairly abundant, though not well-preserved.

East of the farmhouse, the Nant-y-Môch stream cascades over a few feet of hard blue sandy flags, with thin siliceous seams; they strike in a southerly direction, and probably pass underneath the *Dicellograptus* Beds. No fossils were obtained from them. From the cascade to the Rheidol no rock is exposed in the bed of Nant-y-Môch; but, in the centre of the river and along the western bank, blue flags with siliceous and gritty seams occur, which resemble closely the beds at the cascade. The graptolitic beds are probably a thin seam in this mass of blue flags, to which I shall refer as the Nant-y-Môch Flags (see fig. 1, p. 470, and Section No. I on the Map, Pl. XXIV).

From the banks of the Rheidol the section is continued, with but few and unimportant interruptions, along the base and flank of the conspicuous hill Drosgol, which overlooks the valleys of the Rheidol and of its tributary Afon Camddwr flowing in from the north-west. In ascending the section the blue flags give way gradually to dark-blue mudstones with bands of hard grey grit; these are followed by a considerable thickness of coarse deposits consisting of alternations of dark-blue mudstones, grey conglomeratic grits, and gritty or pebbly mudstones. The last-named frequently present a curious gnarled and knotted surface on weathering, which is connected with their internal structure, for a fresh fracture shows numerous dark laminæ twisted and contorted in a remarkable manner. It is not certain whether this contortion results from powerful compression of the rocks, or from a kind of concretionary action after their deposition.

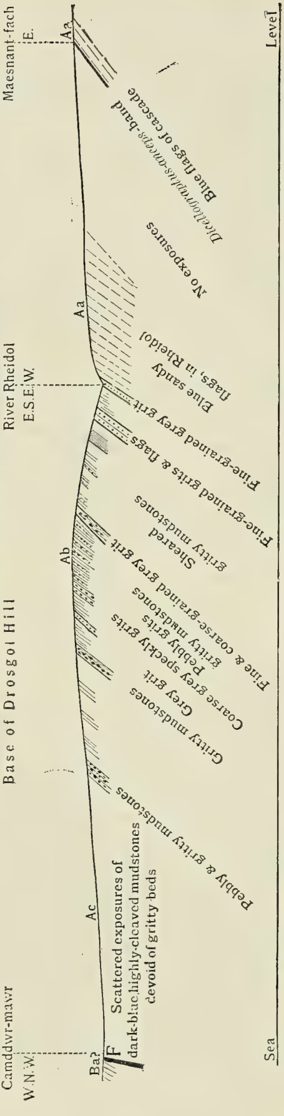
A decidedly conglomeratic appearance is imparted to some of the mudstones by the large well-rounded pebbles of vein-quartz which they contain; these are sometimes aggregated into definite though impersistent bands, but more usually they are thinly scattered in a haphazard fashion throughout the softer sediment. The origin of these curious pebbly mudstones is a puzzling question, for the conditions which allowed quartz-pebbles as large as hens' eggs to be embedded in a matrix of fine mud are difficult to conceive.

In the grits and mudstones alike there are numerous scattered cubes of pyrite, often a quarter of an inch or more in diameter; on exposed surfaces they weather out, leaving a cubical cavity.

The dip of the beds is in a westerly direction, and the bands of grit and conglomerate can be readily followed by the eye as they ascend the flank of the hill towards the summit. To this mass of coarse deposits I have given the name of Drosgol Grits (*Ab*) or Drosgol Beds, from the name of the hill where they are so well displayed.

[1] In order not to encumber the text, the names of authors of species are omitted; they are cited in the general list in Table II, facing p. 530.

Fig. 1.—*Section showing the general relations of the members of the Plynlimon stage near Nant-y-Môch, on the scale of 6 inches to the mile. (Section No. I on the Map, Pl. XXIV.)*



[Aa = Nant-y-Môch Flags; Ab = Drosgol Grits; Ac = Bryn-glâs Mudstones; Ba = Eisteddfa Group; F = Camddwr Fault.]

Resuming the section along the base of the hill, the conglomeratic and gritty beds are succeeded by fine muddy sediments, which crop out in scattered exposures on the grassy slope. On account of the peculiar structural planes which traverse them, the bedding-planes are often impossible to determine; it is, therefore, difficult to say whether the steady dip of the lower beds is maintained in these softer sediments. There is some indirect evidence that they are somewhat folded, but in such a way as to result in a general inclination towards the west.

Compression of these beds has given them a characteristic appearance, which readily distinguishes them from all others that I have seen in the district. An imperfect double cleavage has been set up which causes the rock to split, not in parallel-sided slabs, but in lenticular or phacoidal sharp-edged pieces, the curved surfaces of which are glazed and polished as if they had been black-leaded. I am inclined to attribute this structure, in the main, to the physical constitution of the sediments, perhaps their homogeneity and fineness of grain: for the *Dicellograptus*-Beds below and the great mass of Valentian sediments which succeed

them show, when cleaved, a well-defined parallel structure. I have seen similar structures in other fine-grained sediments which have been subjected to strong lateral pressure, accompanied probably by shearing forces. It is the prevalent structure in the marls in the Old Red Sandstone on the south side of the Pembrokeshire coalfield, where they have come under the influence of the Armorican movement. Also, in the same region, the beds of coal often tend to break up into phacoidal pieces, with extremely sharp edges and highly polished curved surfaces.

A fault of large downthrow towards the north-west brings the mudstone group to an end. It is visible in section near some old heaps of mine-refuse about 300 yards north-east of Camddwr-mawr Farmhouse ; the fault-plane is nearly vertical, and the brecciated material carries a certain amount of galena. The course of the fault along the north-western flank of Drosgol Hill is indicated either by a deep notch, or else by a sharp fall of the ground towards the downthrow side. Its position was accurately indicated on the Geological Survey Map (old series, 59 S.E.) as a metalliferous lode, which at Camddwr is marked as containing lead, while about half-a-mile to the north-east it is labelled as a 'Manganese Vein.'

On tracing the grits and conglomerates which underlie the mudstone group along the summit of Drosgol, they are found to end abruptly against the Camddwr Fault, as it may be called. In this region it forms the northern limit of the ground which I have examined in detail.

Immediately on the north side of the fault, where it is exposed in section, some dark-blue massive mudstones, with well-marked parallel cleavage, dip westwards at an angle of 56° ; their weathered surfaces are stained a light orange colour. Not far below them is an exposure of phacoidal 'black-leaded' mudstones, resembling those forming the western slope of Drosgol on the other side of the fault. The strata immediately succeeding the orange-stained massive mudstones are concealed under the superficial deposits of the valley of Nant-y-Barracks (name on the 6-inch Ordnance map ; on the 1-inch map it is Nant-y-Benglog), which runs in a northerly direction following the strike. On the west side of that valley blue flags and shales, weathering on the surfaces to a bright rusty red, are exposed along an old water-leat. As will be shown below, strata of this character occur everywhere immediately above the base of the succeeding Pont Erwyd Stage, while the orange-stained massive mudstones form the natural upward continuation of the underlying 'black-leaded' mudstones ; these will be referred to collectively as the Bryn-glâs Mudstones (*Ac*) from the name of a prominent hill north of the Aberystwyth-Llanidloes road near Dyffryn Castell. They form the whole of that hill, and in the immediate neighbourhood their relations to the underlying grit group and to the overlying Pont-Erwyd Beds can be clearly made out.

I have found no fossils, either in the Drosgol Grits or in the Bryn-glâs Mudstones.

From this section we learn, therefore, that four groups of rocks, each distinct from the others in its lithological characters, follow one another in regular ascending order from east to west, namely: (1) the Nant-y-Môch Flags, containing *Dicellograptus anceps*; (2) the grits, conglomerates, and mudstones, known collectively as the Drosgol Grits; (3) the blue-black mudstones, for which the name Bryn-glâs Mudstones is suggested; and (4) the red-stained flags and shales, which, as will be shown later, lie at the base of the overlying Pont Erwyd Stage. The first three of these I shall bring together under the name of the Plynlimon Group, to which is therefore given a somewhat more precise significance than was assigned to it by Sedgwick and Keeping.

No other single section gives the relationships of these rock-groups in so clear a manner, but abundant confirmation of the general order here established has been obtained in many parts of the Plynlimon area.

The thickness of the Plynlimon Group is very great, although it is difficult to calculate it accurately; the following estimates of the thickness of the individual members of the group may be of interest:—

	Feet.	
Bryn-glâs Mudstones =	900	(this can be determined accurately.)
Drosgol Grits = about	1500	(fair approximation.)
Nant-y-Môch Flags = about	1000	(doubtful estimate; may be only half as much.)
Total	3400	

To the east of Nant-y-Môch a long undulating slope, on which the underlying geology is almost wholly concealed, rises to within 200 feet of the top of Plynlimon. The western face of the mountain is formed by an escarpment of blue-black mudstones, protected by massive beds of a grey felspathic grit which occupies the summit, and thence falls in gentle undulations towards the east. On the higher ground long, low, wind-swept ridges ranging in a north-and-south direction alternate with peat-covered hollows, in which large blocks of grit tend to accumulate, leaving the intervening ridges bare. Here and there a diminutive tarn occupies the centre of the hollow.

To the north of the cairns, which occur on the summit of the mountain, the ground descends in a succession of rocky escarpments and grass-covered platforms to a small corrie-lake which nestles at the foot about 800 feet below. This lake is one of the sources of the River Rheidol, and bears the name of Llyn Llygad Rheidol (the lake of the eye, or source, of the Rheidol). It is fed by the numerous springs that break out on the face of the escarpment; and the water, being almost free from organic matter, is of a deep blue colour. The town of Aberystwyth, which lies some 14 miles to the westward, obtains most of its water from this lake.

The rocks of Plynlimon may be studied in detail along the steep face overlooking the lake, but their relations are somewhat

disturbed by a fault which traverses the scarp in an east-and-west direction. At one place it was tried for lead.

Starting from the grit at the cairns as a datum-level, the descending section to the fault shows an alternation of grey felspathic grits with blue-black phacoidal mudstones. North of the fault the ground falls gently northwards for about 150 yards, forming a grassy platform; at the end of this space there is an abrupt plunge down to the lake, although the slope is not so steep as to make the rocks inaccessible. In the upper part they consist mainly of gritty mudstones showing gnarled and knotted surfaces on weathering; but in the lower part, just above the lake, large numbers of rounded vein-quartz pebbles, together with big cubes of pyrite, are scattered through the mudstones.

All the rocks in this section bear so striking a resemblance to those of Drosgol that, even if no evidence of their stratigraphical position were forthcoming, one would unhesitatingly assign them to the same general group. In the Plynlimon section, however, the underlying fossiliferous beds of Nant-y-Môch are not exposed; but it will be shown below that the grit-group is succeeded by a great mass of mudstones agreeing in every respect with those that succeed the Drosgol Grits on the west side of that hill.

Returning to the summit of the mountain, the beds of grit which crop out there can be readily traced; and, as their course brings out the structure of this part of the district in a clear and convincing manner, it may be of interest to describe it in some detail.

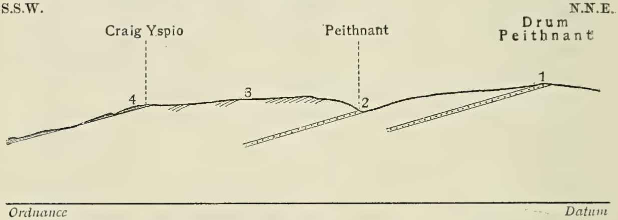
After a few gentle undulations near the cairns, a steady dip to the east sets in which is maintained for nearly 2 miles to the south. The alternations of beds of massive grit and soft mudstones give rise to a series of parallel ridges and hollows on the high ground, which, for a space, divides the drainage of the Rheidol tributaries on the west from that of the Wye tributaries on the east. The strike-features are prominent also down the long slope north of the Peithnant stream. After reaching the bottom of the valley, the grits suddenly swing round to a westerly strike and follow the valley for about 200 yards, then as suddenly turn northwards and range up the hillside with a westerly dip. Some 200 or 300 yards to the west is another outcrop of grits, parallel to the last, but having an easterly dip. These two outcrops probably join on the northern face of Drum Peithnant, somewhere to the east of the cairn, but this cannot be observed. An easterly dip is maintained until the Hirnant valley is reached, where a westerly dip sets in once more.

Such an outcrop is easily explained by the nature of the folding to which the district has been subjected; the rocks are thrown into a series of anticlines and synclines, with a fairly-steady pitch of 12° to 15° in a southerly direction. The axes of the folds range in a direction about south 10° west.

With such a structure, it is obvious that, by starting from the grits at the nose of one of the anticlines or synclines, and proceeding

southwards in the direction of the axis, one passes over the strata which succeed the grits. The best line to take is the one from the anticline at the head of the Peithnant valley, to Craig Yspio about three-quarters of a mile away to the south (fig. 2): where the

Fig. 2.—*Section along the crest of the anticline, from Drum Peithnant to Craig Yspio, on the scale of 2 inches to the mile. (Section No. II on the Map, Pl. XXIV.)*



[1 = Conglomerate and grit, half a mile east of the cairn.
2 = Upper beds of the Drosgol Group (equivalent to the grit-beds on the summit of Plynlimon). 3 = Bryn-glâs Mudstones (*Ac*).
4 = Lower beds of the Eisteddfa Group (*Ba*).]

ground falls abruptly towards the main road, and the anticline is again seen. On the higher ground there are only scattered exposures of blue-black mudstones, breaking up into phacoidal pieces with shiny surfaces; beds of grit appear to be absent.

The rocks exposed in the gullies furrowing the steep slope under Craig Yspio are higher than the mudstones, and consist of blue flags and shales with well-marked parallel cleavage. Their most striking character, however, is the brilliant red-orange colour of their weathered surfaces. This section confirms, therefore, that seen on Drosgol, where, as will be remembered, a great mass of mudstones with peculiar and easily recognized characters intervened between the grit group and the red-weathering shales and flags of Nant-y-Barracks.

As the pitch of the anticline lies between 12° and 15°, the thickness of this mudstone group works out at about 900 feet.

Detailed mapping has shown that the mudstones occupy this position throughout the district. They form the whole of the rather prominent hill of Bryn-glâs, which lies between Pont Erwyd and Dyffryn Castell, from which circumstance I have applied to the group the name of Bryn-glâs Mudstones.

The time at my disposal did not allow me to trace, in detail, the higher beds of the Drosgol Grits from Nant Hirnant to Drosgol, so I have somewhat generalized their outcrop from the scattered observations which I was able to make in that region. If traced in detail, it would probably be found to pursue a zigzag course, as it does to the south of Plynlimon.

B. The Pont Erwyd Stage.

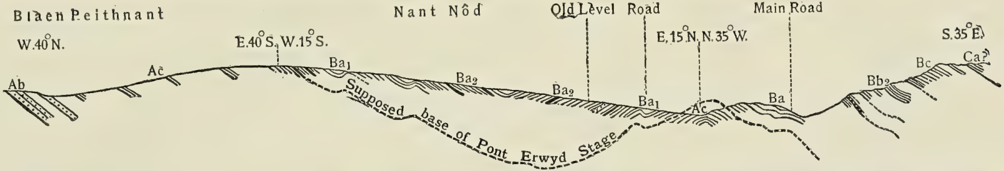
The rocks succeeding the Bryn-glâs Mudstones are well-exposed in many natural sections around the village of Pont Erwyd, which stands near the confluence of the Rheidol and an important tributary, Afon Castell, flowing in from the north-east. They are distributed in two narrow belts, which diverge towards the north in the form of an open V having its apex a little to the south of the village. The eastern belt follows in the main the valley of the Castell, while the western belt skirts the Rheidol valley for about a mile and then gradually bears to the left of that valley. These soft rocks have given rise to the tract of relatively low ground which partly surrounds the higher central tract extending from Bryn-glâs to Plynlimon.

From their splendid development around the village I propose to include them in the Pont Erwyd Stage (B).

In order to study the relations of these rocks to those underlying or overlying them one cannot do better than select a few sections across the Castell and Rheidol valleys, beginning at the eastern edge of the district near Eisteddfa (or 'Steddfa) Gurig, where the order of superposition of the various rock-types is clear and unmistakable.

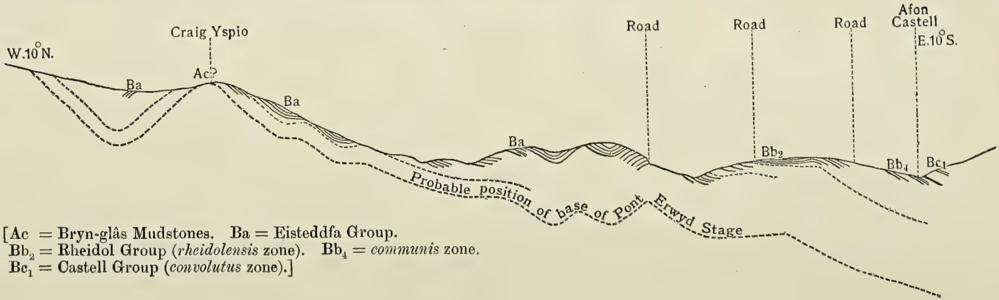
At Eisteddfa Gurig the Tarenig stream, a tributary of the Wye, crosses the main road from Aberystwyth to Llanidloes. It runs there nearly due east and west; but about a quarter of a mile west of the bridge is a right-angled bend, the course of the stream from there to its source on Plynlimon being nearly north and south. At the bend it is joined from the west by a small feeder, Nant Nôd, which has cut a shallow trench through the rocks, thus exposing a fairly continuous section (fig. 3, p. 476). At the junction with Afon Tarenig there is a small waterfall over blue flags, among which are intercalated thin bands of dark-blue pyritous shale; one of these contained an abundance of ill-preserved specimens of *Climacograptus*. Below them are somewhat massive flags and mudstones, which pass down into a few feet of hard gritty mudstones; an occasional specimen of *Climacograptus* was found, but they became exceedingly rare before the gritty beds were reached. The lowest exposed strata are soft, massive, blue-black mudstones, weathering with a light orange-coloured stain. No fossils were found in them, but they resemble those beds which succeed the 'black-leaded' mudstones of the Bryn-glâs Group on the west side of Drosgol. Only a few feet are exposed, the strata then rolling over to the east; and the section along the Tarenig soon comes to an end. The ascending section in Nant Nôd from the sharp bend of Afon Tarenig shows about 300 feet of cleaved dark-blue flags and shales, with occasional hard gritty flags of a paler colour. About 90 yards up stream, at the foot of a small cascade, a graptolitic band (F. 2) yielded the following species in some

Fig. 3.—*Section showing the Pont Erwyd Stage and its relations to the Plynlimon Stage near Eisteddfa Gurig, on the scale of* $5\frac{1}{4}$ *inches to the mile. (Section No. III on the Map, Pl. XXIV.)*



[Ab = Drosgol Grits (upper part). Ac = Bryn-glâs Mudstones. Ba = Eisteddfa Group (1 = *persculptus* zone; 2 = *acuminatus* zone). Bb_2 = *rheidolensis* zone; Bc = Castell Group. Ca = Ystwyth Stage.]

Fig. 4.—*Section from Craig Yspio to Cwm Ergyr, on the scale of* $5\frac{1}{4}$ *inches to the mile. (Section No. IV on the Map, Pl. XXIV.)*



[Ac = Bryn-glâs Mudstones. Ba = Eisteddfa Group.
Bb_2 = Rheidol Group (*rheidolensis* zone). Bb_4 = *communis* zone.
Bc_1 = Castell Group (*convolutus* zone).]

abundance and in good preservation:—*Orthograptus* cf. *truncatus*,[1] *Glyptograptus* cf. *sinuatus*, *Cephalograptus (?) acuminatus*, and *Climacograptus scalaris* var. *normalis*.

The succeeding strata are conspicuous by reason of the brilliant colours, ranging from pale yellow to deep rusty-red, which they assume on weathering, whereby they can often be distinguished from a great distance. A few bands of fine-grained grey grit from 4 to 6 inches thick occur at intervals among the flags and shales. The only fossils obtained were graptolites of the species *Mesograptus modestus* and *Climacograptus scalaris* var. *normalis*. The dip is about 40° in the lower part of Nant Nôd, but diminishes upwards. The total thickness of strata above the gritty bands in the Tarenig, which are provisionally taken as the base of the Pont Erwyd Group, is about 400 feet. Near the ruined buildings of the disused Nant Nôd Mine, the beds turn over to an easterly dip; and in the higher part of the stream the same rocks are exposed in reverse order.

Near an old level on the west side of the syncline, *Cephalograptus (?) acuminatus*, *Climacograptus scalaris* var. *normalis*, *Cl. medius*, and a form suggesting *Mesograptus modestus* (F. 3) were obtained in some red-stained cleaved shales with flaggy bands; and on the tip from an old shaft derived from somewhat lower beds several specimens of a similar form to the last were collected, together with *Climacograptus scalaris* var. *normalis* (F. 4). The red-stained strata are underlain by blue flags and mudstones with occasional specimens of *Climacograptus* sp.; and these by the unfossiliferous Bryn-glâs Mudstones, which are, however, but scantily exposed. About 500 yards to the west is the highest grit-band of the Drosgol Grits, in its natural position below the Mudstone Group.

Summarily stated, this section proves that a group of flags and shales, with a characteristic mode of weathering and containing a few species of graptolites of the family of Diplograptidæ only, overlies the Bryn-glâs Mudstones and Drosgol Grits; the great family of Monograptidæ is not represented in it. The structure is that of a broad and fairly symmetrical syncline, with an anticline on the east.

It will be seen from the map (Pl. XXIV) that the two limbs of the syncline approach one another towards the north, a fact which indicates that the syncline has a southward pitch. The beds near the nose are exposed by the side of the road, about half-a-mile north of Nant Nôd, where they dip at about 18°.

The geological structure is clearly reflected in the form of the ground. The red-stained flags and shales weather readily into small rectangular prisms, while the underlying mudstones resist

[1] The form referred here, and elsewhere in the Pont Erwyd Stage, to *Orthograptus truncatus* differs from that species in some important characters; it is probably a new species. A somewhat similar form was figured as *O. truncatus* var. *abbreviatus* by Miss Elles and Miss Wood in Monogr. Pal. Soc. vol. lxi (1907) pl. xxix, fig. 6 *e*.

the effects of the weather. The centre of the syncline is, therefore, occupied by relatively low, ill-drained ground with a smooth undulating peat-covered surface, whereas the underlying beds stand out as a prominent rocky ridge, forming a rim to the trough of softer rocks. It may be remarked here that this relation of the form of the ground to lithological character has been observed along this junction throughout the district, the passage from the underlying barren mudstones to the graptolitiferous red-stained beds being almost everywhere attended by a sharp change in the appearance of the ground. When this fact is appreciated, the details of the geological structure can be picked out with ease from some point of vantage. It is a little unfortunate that this line does not quite coincide with the base of the Pont Erwyd Stage, which lies about 100 feet down in the underlying mudstones.

If now we take a traverse towards the south-east from the axis of the anticline in Afon Tarenig (fig. 3, p. 476) we pass over the beds with Diplograptidæ once more; they are well-exposed in the road-cutting near the watershed, where they yielded *Climacograptus scalaris* var. *normalis* in abundance. The immediately succeeding strata are not exposed, but on ascending the steep hillside south of Eisteddfa Gurig the rocks are seen to crop out in numerous places, though they are highly-cleaved and fossils are difficult to extract from them. The lowest beds on the slope are flags and shales, with several fine-grained grits up to 8 inches thick; they are followed by a group of blue-hearted shales, with occasional thin flags of a decidedly paler colour. The shales weather deeply to an ashen grey, and their surfaces are stained to various shades of rusty brown; no fossils were obtained in the lower part, but near the top they yielded a few specimens of *Monograptus atavus*, sp. nov., and *M. rheidolensis*, sp. nov. The strata are then concealed for a short space, a slight depression in the hillside suggesting a belt of soft rocks. On resuming the section beyond the depression, one is immediately struck by a great change in the lithological character of the strata. The soft dark-blue shales have disappeared, and their place is taken by very pale greenish mudstones presenting no characters in common with the underlying rocks. They are extremely tough and splintery, and give rise to a precipitous slope with bold crags. It is evident that one is dealing with a new group of rocks wholly distinct in their lithology from those which they succeed, and I propose, therefore, to leave them until the lower group has been more fully described.

We learn from this section that the flaggy beds with Diplograptidæ are followed by more shaly strata, in which occur, for the first time in the ascending sequence, representatives of the genus *Monograptus*, and that these are succeeded by hard pale mudstones. The group at the base of the Pont Erwyd Stage, characterized by Diplograptidæ only, may be named the Eisteddfa Group—a name first given to it by Prof. Charles Lapworth in the appendix to Walter Keeping's paper.

Another section may be taken, about a mile south of the last, from Craig Yspio towards Cwm Ergyr, passing about 300 yards north of that farmhouse (fig. 4, p. 476). For a part of the way it runs nearly parallel with the main road to Llanidloes, as it sweeps round the side of the hill between the 15th and 16th milestones from Aberystwyth. The rocks are well-exposed on the steep slopes north and west of the road, and also in a large number of road-cuttings.

Craig Yspio stands on a spur which projects southwards along the axis of the anticline mentioned on p. 474. The abrupt fall of the ground at the end and round the flanks of the spur is due to the oncoming of the red-stained Eisteddfa Beds above the harder mudstones which form the higher ground.

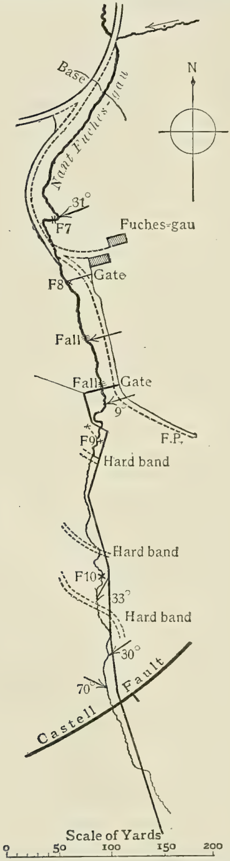
The lowest strata, which are exposed in the line of section, are dark-blue sheared-looking mudstones, belonging probably to the Bryn-glâs Group. They are followed by flags with thin grits and containing an occasional specimen of *Climacograptus scalaris* var. *normalis*; these pass up into flags and shales with thin siliceous seams, weathering in brilliant red and orange colours which render them remarkably conspicuous from a great distance. Though the rocks are highly cleaved, graptolites of the genera *Climacograptus* and *Diplograptus* can be obtained in several places; but the best specimens were found on the west side of the well-defined syncline which lies to the west of the Craig Yspio anticline. The following specimens were collected near the base of the group, in a strike-gully lying high up on the steep slope west of Pont Nant Lladron, and plainly visible from the main road (F. 5):—*Mesograptus modestus* and its variety *parvulus*, *Glyptograptus persculptus (?)*, *Gl.* sp., and *Climacograptus scalaris*, vars. *normalis* & *miserabilis*.

North of the 15th milestone from Aberystwyth, the red-stained strata form prominent crags by the side of a small stream which crosses the road near the milestone. What are probably the same rocks are exposed in the road-cutting 250 yards to the east, where the section shows a succession of shallow anticlines and synclines, the effect of which is gradually to introduce higher beds towards the east. All the rocks are cleaved, and the difference between this structure in the soft shales and in the interbedded flags is strikingly exhibited, especially on weathering. The shales break up into small pieces as thin as paper, while the flags (having developed a much coarser structure) part into rhomboidal prisms. Strata of this character extend for about a quarter of a mile; but, for some part of this distance, the road runs nearly along the strike.

After crossing a small stream, which flows past some old spoil-heaps, soft orange-weathering shales predominate for about 100 yards, then giving way to hard blue sandy shales with rather thick flags which persist to the point where the road sweeps round to the north towards Eisteddfa Gurig. These higher shales weather to a dull bronze-brown, in this respect and in their more

sandy character contrastingly strongly with the underlying beds. In them I found *Monograptus rheidolensis* and *Climacograptus* sp.

Fig. 5.—*Plan of the Fuches-gau locality, on the scale of 12 inches to the mile.*



At the bend where the road-section terminates, a bedding-plane is exposed which is covered with a matted aggregate of *Monograptus atavus*, sp. nov.

On the slope leading down to the valley east of the road are a few exposures of soft, blue, massive mudstones and flags. Close beside the stream, a band of cleaved shale in them yielded (F. 6) *Monograptus triangulatus*, *M. communis*, *M. revolutus (?)*, *M.* cf. *fimbriatus*, *M. gregarius (?)*, *M. attenuatus (?)*, and abundance of *Climacograptus törnquisti*. About 20 yards away on the east side of the valley pale greenish mudstones, similar to those near Eisteddfa Gurig (p. 478), are exposed.

This section confirms the previous one as regards the relation of the *Diplograptus* Beds to the unfossiliferous Bryn-glâs Mudstones, the oncoming of strata with *Monograptus*, and the marked change from the dark-blue shaly type of sediment to the pale greenish mudstones; moreover, a glimpse is obtained of the rocks immediately underneath the latter, which were concealed in that section.

From the syncline to the west of Craig Yspio, the base of the Eisteddfa Beds strikes steadily southwards, and passes behind the Dyffryn Castell Hotel. Characteristic graptolites were obtained at several

points. In some places the fossiliferous beds are underlain by a few feet of dark-blue, flaggy, pyritous mudstones, with bands of grit 3 to 6 inches thick.

The Eisteddfa Beds next appear in the small stream called Nant Fuches-gau, which flows northwards past the farm of the same name, to join the Castell river about half a mile west of the Hotel. The Bryn-glâs Mudstones are exposed in the stream as well as in Nant Fuches-wen, which joins the former just where it passes under the Devil's-Bridge road, and also in a road-cutting near by. They present their usual characters of blue-black, apparently crushed mudstones, which break up into fragments with curved shiny surfaces; and they occur at intervals for about 60 yards up Nant Fuches-gau. At this point is a quartzitic band 2 or 3 feet thick, which is followed for about 20 yards by sandy micaceous mudstones with some pyrite. These mudstones, in the lower part, have the crushed appearance characteristic of the Bryn-glâs Group; but, in ascending the section towards the south, they are seen to become less sandy and micaceous, and gradually to assume the smooth flaggy characters of the rocks of the overlying group. No fossils were obtained in this part of the section; but a few yards farther south, a band of highly pyritous shale crowded with graptolites was found at a right-angled bend in the stream, below the ford leading to the farmyard (see fig. 5, p. 480). The following species have been identified from this locality (F. 7):—*Mesograptus modestus* and its variety *parvulus*, and *Glyptograptus persculptus*, the two last-named being abundant and in beautiful preservation. The strike of the beds is nearly parallel to the stream at this point, and the dip is about 30° in a westerly direction.

Immediately beyond the first fence (F. 8), south of the ford, hard blue flags with darker pyritous bands yielded a large number of the following graptolites, beautifully preserved in full relief in pyrite: — *Climacograptus scalaris* vars. *normalis* & *miserabilis*, *Glyptograptus persculptus*, and *Mesograptus modestus (?)*.

These beds are probably about 20 feet above those of F. 7.

About 40 yards up stream similar, though somewhat higher, rocks are exposed in the sides of a small waterfall; and near the gate which leads to the moorland on the east of the stream another small fall occurs, over still higher beds. In ascending the section the proportion of shales to flags gradually increases, and a pronounced red and yellow weathering of the strata sets in, which is hardly noticeable in the lower beds. About 40 yards south of the gate, the stream is crossed by another fence, beyond which is an exposure of flaggy shales with thin flags and white siliceous stripes. They contain pyrite in the form of minute globules, which on weathering out leave a multitude of small hemispherical cavities on the flat surfaces of the beds. These shales are of a peculiar granular texture, and break rather like cardboard.

Graptolites are fairly plentiful, preserved either in full relief in pyrite or in low relief in a greenish-white substance; the following were identified (F. 9):—*Orthograptus* cf. *truncatus* (v.c.), *Mesograptus modestus?* (r.), *Cephalograptus (?) acuminatus* (v.c.), *Climacograptus scalaris* vars. *normalis* & *miserabilis (?),* and *Cl. medius.*

These beds are followed by hard blue flags and blue and olive-green gritty shales, weathering deeply to a buff colour with brown and yellow stripes. They contain three bands of tough olive-green gritty mudstones, which give rise to small waterfalls. Towards the upper part of the section the surfaces of the rocks are so deeply stained to a bright orange colour that it comes off on the fingers. The fresh rocks were probably calcareous, and some of the beds remind one of rottenstones in their mode of weathering. Graptolites are not plentiful, and are for the most part poorly preserved. They are of the same species as those just enumerated; with, in addition, *Mesograptus modestus* var. *diminutus* (c.), and a well-preserved *Dictyonema* sp.: also a species of *Orthoceras*, which was rather common (F. 10). The section ends about 300 yards south of the gate mentioned above, the stream being crossed hereabouts by an important fault with a downthrow to the south.

This section illustrates the difficulty of finding a definite base-line to the Eisteddfa Beds. There seems to be a gradual change in the lithological characters of the strata from the crushed-looking sheeny mudstones of the Bryn-glâs Group, devoid of fossils, to the smooth, flaggy, red-weathering strata with Diplograptidæ. I have adopted, for want of better, the thin quartzitic band exposed in the stream about 150 yards north of Fuches-gau as the line of separation in this section; it may correspond to the gritty horizon which was adopted as the base-line in the Afon Tarenig section (see p. 475).

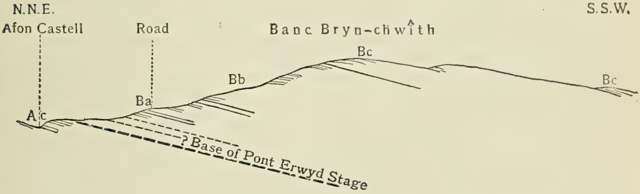
The group thus limited is characterized by the prevalence of forms of *Mesograptus modestus*, which appear earlier than *Cephalograptus (?) acuminatus.* The flaggy mudstones with *Mesograptus modestus* var. *parvulus* and *Glyptograptus persculptus*, which occur near the base of the group, may well be separated off as a distinct zone, and this may be called for short the *persculptus* zone. The zone of *Cephalograptus (?) acuminatus* (or *acuminatus* zone) then commences with the red-weathering flags and shales.

From Nant Fuches-gau the strata swing round to a westerly strike, and range towards Pont Erwyd. The base runs for some distance parallel with, and north of, the road to Devil's Bridge. South of the road are several exposures of rusty flags and shales, which weather down into small rectangular fragments; in them are some hard thickly-bedded grits and gritty mudstones, which

appear to correspond with those in the stream-section on the east.

Although the base-line hereabouts seems to follow a fairly straight course from east to west, if it could be observed in detail it would probably be found to be an undulating line, since the Eisteddfa Beds on the south and the Bryn-glâs Mudstones on the north are traversed by numerous shallow folds which have a steady southward pitch of about 12°. A section showing the general order of superposition of the strata may be obtained along the slopes of Banc Bryn-chwîth by following the direction of the pitch of the folds from the base to the summit of the hill (see fig. 6). As a section of this kind is likely to be free from strike-faulting, it furnishes a reliable estimate of thicknesses—provided that the pitch be known.

Fig. 6.—*Section along the pitch of the folds, from the Afon Castell over Banc Bryn-chwîth, showing the general relations of the rock-groups. (Section No. V on the Map, Pl. XXIV.)*



[Scale: 6 inches=1 mile.]

[Ac=Bryn-glâs Mudstones. Ba=Eisteddfa Group.
Bb=Rheidol Group. Bc=Castell Group.]

The Bryn-glâs Mudstones (*Ac*) are exposed in the bed of the Afon Castell, and in small bosses on the peaty ground between that river and the Devil's Bridge road. The red-stained flags and shales (*Ba*), with abundant *Climacograptus* and occasional *Diplograptus*, form the steep slope south of the road, and are succeeded near the summit by dark-blue shales (*Bb*) with *Monograpti*; while the hill is capped by pale greenish-blue mudstones (*Bc*), striped with seams of sandy material. The same order is, therefore, preserved as in the former sections; the thickness of the Pont Erwyd Stage below the pale mudstones is about 660 feet.

I may now pass on to the description of the magnificent section exposed in the deep gorge of the Rheidol below the village of Pont Erwyd (see Pl. XXV). This is by far the most important section in the district, and the succession can be studied in great detail: consequently, although the strata are in several places highly

folded and broken, there can be no doubt as to their original order of superposition. Furthermore, graptolites occur in abundance and in exceptionally good preservation, and the general absence of cleavage renders their extraction easy.

On a broad view, the structure of the gorge resolves itself into a faulted anticline, east of which is a shallow syncline. As the gorge winds backwards and forwards across the strike, it follows that the same strata are exposed in several parts of the river-bed: and, for this reason, it is a little difficult to choose a starting-point for the description of the section. As it seems desirable to deal with the rocks as far as possible in ascending order, I shall commence with that part of the gorge where the lowest beds are exposed. This lies at the bend of the river 500 yards south-south-east of the bridge, and a little below the end of the plantation which skirts the south side of the gorge from near the Gogerddan Arms Hotel. On the east side of the river are some hard sandy flags with shales yielding *Cephalograptus (?) acuminatus* and *Climacograptus scalaris* var. *normalis.* Near the centre of the river-bed the strata are violently contorted, and I only found a single specimen of *Climacograptus medius.* When the river is low, it flows close to the western bank along a fault-line which throws down somewhat higher strata on the west. These consist of flags and shales, with three gritty bands which stand out prominently in the bed of the river. The lowest is a tough grit, which is truncated by the strike-fault and jammed against the older beds on the east. The middle band is made up of alternations of flags and shales, and beds of hard blue grit with cubes of pyrite. The highest band, which is also the thickest, consists of massive grits, gritty mudstones, and flags, the whole being about 18 feet thick. This band enters the southern bank of the gorge exactly opposite the end of the plantation, but reappears in the river-bed about 170 yards to the south. A few yards below it is a similar band, which may be a repetition of the first by a strike-fault; but it is more likely that it corresponds with the middle band seen higher up the river, although the thickness of beds between them does not quite match in the two places.

The strata succeeding the highest band are completely exposed between its outcrop and the next bend of the Rheidol, where a small tributary enters from the west. Their lower part consists of flags and shales; but the proportion of shaly material so increases in ascending the section that near the bend shales predominate. They weather to a pale yellow as a rule; and their surfaces are sometimes minutely pitted, owing to the removal of globules of pyrite. In the lower beds *Climacograptus scalaris* var. *normalis* was almost the only fossil found; but in the higher and more shaly beds *Monograptus atavus*, sp. nov. occurred frequently along with it. The dip in this part of the river is due west; but close to the bend the strata are folded into a sharp syncline followed on the west by an equally sharp anticline, the axes of which are only about 15 yards apart

and range in a direction south 10° west; the pitch is 12°. As the rocks are laid bare for a considerable distance in the bed of the river, these pitching folds are beautifully displayed in plan. On the axis of the anticline close to the bank of the river a shaly band (F. 11) yielded the following graptolites :—*Monograptus atavus* (v.c.), *Dimorphograptus erectus*, and *Climacograptus scalaris* var. *normalis*; while a few yards away, at about the same horizon, *Cl. törnquisti* occurred in abundance. As the river swings round to the east, the same rocks are passed over in reverse order, until, about 200 yards below the bend, a band of grit crosses the river, which lies exactly in the line of strike of the highest band mentioned above. Immediately below it I found *Cephalograptus (?) acuminatus* and a *Climacograptus*. Some 18 yards away another band of grit emerges from the northern bank of the river, but only reaches mid-stream, being there truncated by a strike-fault of considerable throw. The fracture is so clean-cut that it escaped my attention for a long time, and the abrupt ending of the grit band puzzled me considerably. A shaly film within an inch or two of the fault on the west side afforded many specimens of *Mesograptus modestus*, together with *Cephalograptus (?) acuminatus*. The occurrence of these species proves that the strata up to the highest grit band belong to the *acuminatus*-zone of the Eisteddfa Group.

The first species of *Monograptus* appears some distance up in the succeeding beds, and is there accompanied by that peculiar genus *Dimorphograptus*, which forms, as it were, a connecting link between the Diplograptidæ and the Monograptidæ.

On the east side of the fault are some shales and thin flags which resemble the beds with *Monograptus atavus*, but the characteristic fossil was not obtained. In a few yards they roll over to the east in an anticline with the usual southerly pitch; this fold is one of the leading structures of the gorge.

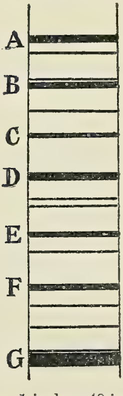
Immediately east of the crest is a line of small calcareous nodules, which seems to mark a slight change in the physical conditions: for the succeeding strata are somewhat harder and more sandy with a smaller proportion of shales; while they weather a dark rusty brown, in contrast with the pale orange colours of the underlying beds. This change is also accompanied by a change in the fauna, for the characteristic graptolite of the higher beds is *Monograptus rheidolensis*, sp. nov. This form can be obtained in considerable numbers at the point numbered F. 12 in the gorge. It is accompanied by *Monograptus attenuatus*, *Orthograptus mutabilis* (c.), *Glyptograptus tamariscus*, *Dimorphograptus confertus* cf. var. *swanstoni*, *Climacograptus rectangularis*, *Cl. scalaris* var. *normalis* (c.), and *Cl. törnquisti* (v.c.).

I propose to include the rocks above the line of small nodules in the zone of *M. rheidolensis*, which, although less abundant than *Cl. törnquisti*, has a smaller vertical range. The part of the gorge where they crop out runs nearly due north and south, but soon swings round to the east again. At the elbow a band of large calcareous

nodules occurs, which can usually be seen near the southern bank when the river is low. They are chosen as the upper limit of the *M.-rheidolensis* zone, for the beds above these nodules are somewhat shaly and are remarkably rich in graptolites, many of the species of which have not been observed at a lower horizon. These beds are only about 40 feet thick; but, owing to the numerous undulations and small faults which traverse them, they occupy the bed of the river for about 400 yards across the strike. Their upper limit is marked by another layer of large calcareous nodules, exposed in the side of an old water-leat, made along the gorge many years ago in order to supply some lead-mines lower down.

Immediately beneath the lower nodules, in the crest of a small anticline east of F. 13, *Monograptus incommodus* was obtained, together with *Orthograptus mutabilis* and *Climacograptus hughesi*.

Fig. 7.—*Vertical section through a part of the* cyphus *zone, showing the 'pattern' formed by the flaggy beds.*



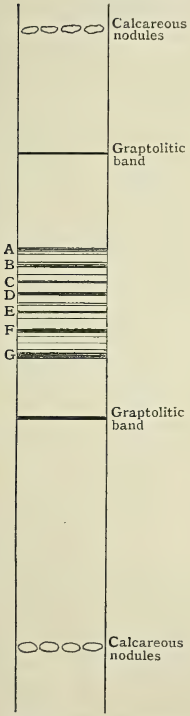
[Scale: 1 inch = 40 inches.]

For some distance the fossiliferous beds underlying the upper nodules dip towards the leat, and extensive bedding-surfaces are laid bare; some of these are covered with species of *Monograptus* (chiefly *M. atavus*), which frequently reach a length of 2 or 3 feet without any appearance of a beginning or of an end.

A lithological peculiarity of these strata may be mentioned here, as by its means I was enabled to piece together the detailed structure of this part of the gorge despite numerous undulations and faults, and to connect up the sequence across a 'crush-belt' which obliterates for a space the stratigraphical relationships. In the dark-blue shaly beds there are sandy flags of a paler colour, which vary in thickness from mere stripes to about 3 inches. The thicker flags occur at fairly-regular intervals, and the spaces between them are occupied by several of the thinner flags forming a 'pattern', which on a waterworn surface is rather conspicuous (see fig. 7). The character which attracted my attention was the remarkable persistence of these flaggy bands as the beds are traced along the gorge, and after a little practice it became an easy matter to identify certain conspicuous 'patterns' on opposite sides of a small fault or crush-belt. I could detect no appreciable variation in the thickness or spacing of the thicker flags in a distance of nearly a quarter of a mile along the gorge. Having in this manner established the stratigraphical order of the beds, I was able later to

confirm it by noting the position of rich graptolitic horizons with reference to some 'pattern' which could be easily recognized. Also the upper layer of nodules which is exposed near the commencement of the water-leat, 14 feet above A, the top of the 'pattern', is found again 400 yards lower down the gorge occupying the same relative position. For the guidance of those who may visit this section, the outcrops of the nodule-layers and of the top and bottom of the group of most conspicuous 'patterns' are shown on the enlarged plan of the gorge (Pl. XXV). Also the diagram of these 'patterns', and the position with reference to them of certain rich graptolitic horizons, may prove of use. It will be observed that the thinner flags between the thicker flags labelled A–G are differently grouped in each space; their use in identifying a stratigraphical horizon is, therefore, not unlike the use of the Frauenhöfer lines in identifying parts of a solar spectrum.

Fig. 8.—*Vertical section through the* cyphus *zone, Rheidol gorge.*



[Scale: 1 inch = 10 feet.]

The 40 feet of strata included between the upper and lower nodule-layers contain several graptolitic horizons. Two of these may be more especially mentioned: the lower is about 25 feet below the upper nodules, or a few feet below the rather thick flag G. It is most easily accessible in the side of the water-leat, about 50 yards west of the anticline which brings up the lower nodule-layer on the south side of the gorge.

The rocks dip towards the leat, and large slabs can be easily removed (F. 13). The species collected here include:—*Monograptus atavus* (v.c.), *M. cyphus* (s.s.), *M. revolutus* and its variety *austerus*, *M. rheidolensis (?)*, *M. sandersoni*, *Orthograptus mutabilis*, *Glyptograptus sinuatus*, *Gl. tamariscus*, *Climacograptus hughesi* (c.), *Cl. scalaris* var. *normalis*, *Cl. törnquisti* (c.). The other horizon is about 6 feet below the upper nodules, or 8 feet above A, the top of the 'patterns'; it can be most conveniently examined in the side of the leat, about 50 yards down the river from the point where a

small tributary enters from the north (F. 14). The graptolites are beautifully preserved in full relief in pyrite, and occur in great abundance. The following forms have been identified:—*Monograptus atavus* (c.), *M. attenuatus*, *M. cyphus* (s.s.) v.c., *M. gregarius*, *M. inopinus (?)*, *M. revolutus* and var. *austerus*, *M. sandersoni*, *Orthograptus mutabilis* (v.c.), *O.* cf. *penna*, *Glyptograptus tamariscus* (c.), *Climacograptus hughesi*, and *Cl. törnquisti* (c.). The strata between the two layers of calcareous nodules may be called the zone of *Monograptus cyphus* (or *cyphus* zone), after that graptolite which appears to be almost confined within these limits.

The upper layer of nodules ushers in a new set of beds, readily distinguished by their lithological and faunal characters from the underlying strata. They are exposed on both sides of the river south-west of Ty'n-y-ffordd Farm, but are more easily reached on the west side where they dip west-south-westwards at 25° to 35°. The section shows alternations of massive blue mudstones and dark-blue shales which are abundantly graptolitiferous: each band containing some forms peculiar to itself, as well as others which are common to more than one band:—

	Thickness in feet	inches.
(9) Pale greenish mudstones, with sandy stripes; only lower part seen.		
(8) Dark-blue graptolitic shales and mudstones, with a pale-green flag near the centre	2	6
(7) Greenish-blue thickly-bedded mudstones, somewhat darker than 9	23	0
(6) Dark-blue mudstones, with graptolites	0	6
(5) Blue flags and mudstones	3	0
(4) Dark-blue ferruginous shales; graptolites abundant.	4	6
(3) Blue mudstones, with a layer of calcareous nodules about 2 inches in diameter at the base	3	6
(2) Dark-blue ironstained shales, with flags of a paler colour, especially in the lower part; graptolites throughout	20	0
(1) Blue thickly-bedded mudstones	6	6
Layer of large calcareous nodules (up to 1 foot in diameter).		

The mudstones intervening between the dark graptolitic shales are decidedly paler in colour, and contain relatively few and ill-preserved graptolites, which are, therefore, difficult of identification.

From the lowest shale band (2) the following forms were obtained (F. 15):—*Monograptus atavus* (c.), *M. attenuatus*, *M. communis*, *M. concinnus* (c.), *M. cygneus (?)*, *M. fimbriatus*, *M. gregarius*, *M. revolutus* (v.c.) and var. *austerus*, *M. sandersoni*, *M. triangulatus* and var. (c.), *Orthograptus* cf. *bellulus*, *Glyptograptus tamariscus*, *Petalograptus palmeus*, *Climacograptus hughesi*, *Cl. törnquisti* (v.c.), *Orthis (?)*, and fragments of *Orthoceras* or *Conularia*.

The most characteristic form is a variety of *Monograptus triangulatus*, which has shorter and blunter thecæ than is considered typical. The graptolites are preserved in low or in full relief.

The next higher shale band (4) afforded the following forms

(F. 16):—*Rastrites approximatus*, *R. longispinus*, *Monograptus atavus*, *M. communis* (c.), *M. concinnus*, *M. fimbriatus*, *M.* cf. *fimbriatus*, *M. gregarius*, *M. revolutus (?)*, *M. triangulatus* (c.) and var., *Orthograptus* cf. *bellulus*, *O. insectiformis* (c.), *Glyptograptus sinuatus*, *Gl. tamariscus*, *Climacograptus hughesi*, and *Cl. törnquisti* (v.c.).

The genus *Rastrites* makes its first appearance in the ascending sequence, and the usually rare form *Orthograptus insectiformis* occurs here commonly. *Monograptus revolutus*, so abundant on lower horizons, has almost if not quite disappeared; while other species which occur with it there linger on into this band. The typical form of *Monograptus triangulatus* is abundant, while the variety mentioned above occurs less commonly. The graptolites are mostly preserved in full relief, and many of the specimens are very beautiful.

The thin band of dark mudstones (6) is distinguished by the abundance of *Mesograptus magnus*, which makes its first appearance at this level (F. 17). This species was described by Dr. Herbert Lapworth from an exactly corresponding position in the Rhayader district. In the Rheidol section it is associated with the following forms:—*Monograptus argutus (?)*, *M. attenuatus*, *M. concinnus (?)*, *M. communis* var., *M.* cf. *millipedia*, *M.* cf. *triangulatus*, *Rastrites approximatus*, *R. longispinus*, and *Climacograptus törnquisti*.

The form referred to *Monograptus communis* occurs as abundantly as *Mesograptus magnus*, and appears to be restricted to this horizon and the overlying *leptotheca* band; it is different from the *M. communis* of band No. 4.

The flaggy beds succeeding the *magnus* band become progressively paler in colour upwards, and approximate in their lithological characters to the main mass of mudstones which conclude the section at this locality. The highest graptolitic band (8) occurs in these pale mudstones, and is perhaps the most interesting bed in the whole district, on account both of the beauty and variety of its graptolites and of its extraordinary persistence with the same characters throughout the district. The following are the forms identified from this locality (F. 18):—*Monograptus* cf. *argenteus*, *M. argutus* (c.), *M. communis* var., *M. concinnus*, *M. cygneus*, *M. gregarius*, *M. inopinus*, *M. leptotheca* (c.), *M.* cf. *millipedia* (v.c.), *M.* cf. *mirus*, *M. revolutus (?)*, *M.* cf. *urceolus*, *Mesograptus magnus*, *Glyptograptus tamariscus*, *Petalograptus palmeus* and var. *tenuis*, *Climacograptus hughesi* (v.c.), and *Cl. normalis (?)*.

The affinities of this band, which may be designated the *leptotheca* band, are on the whole with the underlying beds, and I have drawn the base of the succeeding group above it.

Near the centre of the dark-blue mudstones occurs a thin flag (about three quarters of an inch) of a very pale rock with greenish stripes; it resembles somewhat the main mass of pale mudstones which succeed the graptolitic band, but is decidedly lighter in colour and has a peculiar greenish tinge. It has been found in this position

wherever the band was examined. As will be shown in the sequel, there is reason to believe that this peculiar rock has a wide distribution outside the district here described. The beds between the calcareous nodules at the base and at the top of the dark band (8) are characterized by forms which may be grouped around *Monograptus communis*, and may therefore be referred to the zone of that graptolite. The rocks of this part of the Rheidol section may, then, be summarized as in the following table:—

				Thickness in feet	inches.
Pont Erwyd Stage.	Castell Group.	Pale mudstones.			
	Rheidol Group.	Zone of *Monograptus communis*.	*Leptotheca* band. *Magnus* band. *Triangulatus* band. *Triangulatus*-var. band.	63	6
		Zone of *Monograptus cyphus*		40	0
		Zone of *Monograptus rheidolensis*		160	0
		Zone of *Monograptus atavus*		150	0
	Eisteddfa Group.	Zone of *Cephalograptus (?) acuminatus*; seen to about		50	0

It will be seen from the table that in this section there is a thickness of over 400 feet of beds between the Eisteddfa Group and the base of the pale mudstones which are assigned to a higher group. They are characterized by a large number of species of *Monograptus* and *Rastrites*, and by some well-marked forms of Diplograptidæ. I propose to denote the group as the Rheidol Group.

In accordance with the anticlinal arrangement revealed by the lower beds in the gorge, the black shales of the *M.-communis* zone swing up the hillside along the base of the precipitous crags overlooking the river opposite Bryn-chwîth Farm, where the strong jointing of the overlying *M.-convolutus* beds is remarkably conspicuous. The highest beds just reach the top of the hill, and then immediately meeting the axis of the anticline roll over to the west. Along the hilltop the course of the anticline which brings these soft strata to the surface is indicated by a narrow depression, bounded by rocky ridges of pale mudstones. In about a quarter of a mile the outcrop of the black shales intersects another of the great meanders of the Rheidol, 300 yards north of the Parson's Bridge. For nearly half a mile above this point the direction of the river is determined by an important fault which locally carries lead-ore; the fracture can be seen in several places in the bed and banks of the river, and also in a gully on the west which follows the line of weakness. The black shales on the north of the fault are thrown against pale gritty mudstones on the south,

which, as will be shown on p. 503, form part of the overlying Castell Group. The section here closely resembles the upper part of the one that has already been described in detail. There are, however, two bands of calcareous nodules, including about 5 feet of black shales, near the base of the shale-group. Above these are two prominent shale-beds separated by massive flags of a paler colour. These two contain the characteristic graptolites of the *triangulatus* bands. A few feet above the upper is a thin band of flaggy shales, containing abundance of *Mesograptus magnus* and *Monograptus communis* var. The succeeding flags, which are paler in colour, are seen to a thickness of about 20 feet, when the section is concealed for a space by débris and fallen blocks. This deficiency is made up for by the exposures along the old leat, which has been cut in the side of the hill some distance above the river-level. There the *leptotheca* band with the pale-green flag at the centre yielded its characteristic fossils ; moreover, the *magnus* band (F. 19), with *Rastrites approximatus*, *Monograptus argutus*, *M. communis* var., *M. gregarius*, *Mesograptus magnus*, *Petalograptus* cf. *minor*, and *Climacograptus rectangularis*, occurs at about the same distance from the *leptotheca* band as in the main section. Below that again is the higher of the *triangulatus* bands; the lower band was not identified with certainty in the leat, but as the beds roll over hereabouts, probably the section does not descend to that level.

If now we return to the point where we commenced our examination of the gorge, and proceed up the river from the highest grit band exposed there, we find precisely the same general sequence of rock-types; but, owing to the prevailing cleavage and to the frequent belts of sharp folding, fossils are more difficult to obtain, and the thicknesses cannot be accurately determined. It is unnecessary to do more for this section, than to mention a few important points.

About 100 yards below the point where the Llewernog falls into the Rheidol, near the Hotel, a thin bed of shale (F. 20) yielded abundant well-preserved specimens of *Monograptus atavus (?)*, *M. rheidolensis*, together with *M. sandersoni*, *Orthograptus mutabilis*, *Glyptograptus tamariscus (?)*, *Climacograptus hughesi*, *Cl. scalaris* var. *normalis (?)*, and *Cl. törnquisti*. About 50 feet higher is a layer of calcareous nodules which introduces the black-shale group, at the top of which lies the *leptotheca* zone followed by the pale mudstones. The sides of the gorge are here precipitous and inaccessible, but the characteristic fossils of the *magnus* and *leptotheca* bands were collected from some cleaved beds on the top of the cliff. In the latter *Monograptus* cf. *argenteus* was found in considerable numbers ; the green flag also occupied its usual position at the centre.

The loop of the gorge which lies nearest the main road affords another confirmatory section. The calcareous nodules are seen there also, and some distance below them were found good specimens of *Monograptus rheidolensis*. These rocks are, however,

difficult of access, owing to the precipitous character of the walls of the gorge.

This concludes our examination of the Rheidol Group in the region around and to the east of Pont Erwyd; there remains only the northern belt along the west side of the Rheidol Valley.

The general sequence in that area tallies so exactly with that observed in the other regions, that it is unnecessary to describe all the sections, and I shall only refer to one which exhibits some slight differences from those already described. This is found in and near a small stream which flows past the farm of Gwenffrwd-uchaf, about 2 miles north-west of Pont Erwyd. Opposite the southernmost farm-building is an exposure of dark-blue shales and massive mudstones which weather deeply in patches to a buff colour with limonitic stains (F. 21). They yielded *Climacograptus medius* in some abundance, together with *Orthograptus vesiculosus* and a form which suggests *Dimorphograptus extenuatus*; but the majority of the fossils are indifferently preserved. I have not met with this assemblage anywhere else within the district; the lithological character of the beds and their mode of weathering recall the higher part of the Eisteddfa Group in Nant Fuches-gau. They probably lie at the top of the *acuminatus* zone or at the base of the *atavus* zone. The section in ascending order is continued up stream in soft dark shales with grey stripes from an eighth to a quarter of an inch thick; they yielded no fossils, but are not unlike the beds of the *atavus*-zone. The pale mudstone group commences about 200 feet above the beds near the farm, and immediately underneath them I obtained *Monograptus fimbriatus*. If the reference of the fossiliferous beds to the *atavus* zone is correct, then either the succeeding strata must be much attenuated in this district, or (as is more probable) some beds are faulted out; the rocks beneath the pale mudstone group are greatly disturbed.

An interesting exposure of the *leptotheca* band occurs at the entrance to an old quarry near the stream, about 300 yards north-east of Gwenffrwd-uchaf Farm. It is almost the lowest bed in the quarry, and is exceedingly rich in graptolites, among which *Monograptus* cf. *argenteus* is especially abundant (F. 22). That form seems, however, to have a very restricted range in the band: for it is extremely difficult to find specimens unless the exact layer is hit upon, when they can be obtained in plenty. The full list from this locality is as follows:—*Rastrites approximatus*, *Monograptus* cf. *argenteus*, *M. argutus*, *M. gregarius* (c.), *M. leptotheca*, *M.* cf. *millipedia*, *M.* cf. *mirus*, *Orthograptus vesiculosus* var. *penna*, *Glyptograptus sinuatus*, *Gl. tamariscus*, *Climacograptus hughesi*.

It is an interesting fact that the pale-green flag noted in several other localities is found here also, occupying its usual position near the centre of the graptolitic shales.

The higher strata of the Pont Erwyd Stage: Castell Group (*c*).

It has been repeatedly mentioned that the upper beds of the Rheidol Group are normally followed by pale mudstones, differing markedly in their lithological character from the underlying dark-blue shales. The palæontological features of this new group, and its relationships to the underlying and overlying strata, are nowhere more clearly exhibited than along the southern flank of the Castell Valley, and for this reason I propose to call it the Castell Group.

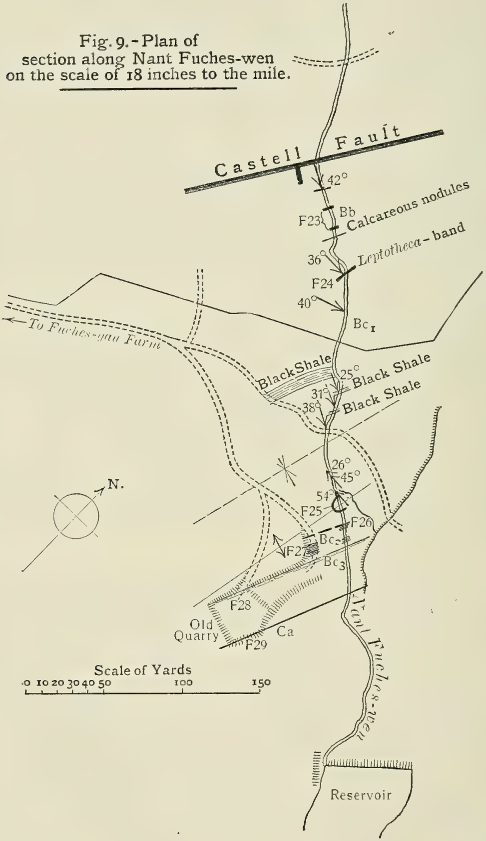
The fault which brings the pale mudstones against the black shales in the Rheidol Gorge has been traced, in a north-easterly direction, into the Castell Valley, the south side of which it skirts for nearly 2 miles, finally leaving it near Cwm Ergyr. Its course is indicated by numerous workings in, and trials for, lead- and zinc-ores. The amount of its throw varies somewhat in different parts; but, so far as I have traced it, the downthrow is always to the south-east. It usually brings the pale mudstones against various members of the Rheidol Group, but in places small areas of the latter beds appear on its downthrow side, especially along the more important anticlinal folds. It is exposed in several artificial sections near the Dyffryn Castell Mine (or West Esgair Lle Mine, as it is named on the 6-inch Ordnance Survey map), which is one of the few mines still at work in this district.

The most instructive sections through the group are (*a*) Nant Fuches-wen, which enters Nant Fuches-gau at the Devil's Bridge road near Troedrhiwgoch; (*b*) Nant Meirch, a small stream which joins the Afon Castell from the west, near the Dyffryn Castell Hotel, and the hillside to the south; and (*c*) the steep slope south of Eisteddfa Gurig.

(*a*) Nant Fuches-wen.—For nearly 300 yards to the east of the main road this stream flows in a shallow gorge cut in the higher strata of the Bryn-glâs Group, after which there is a space of about 120 yards where no rock is visible. The section (see fig. 9, p. 494) recommences in blue flags with thin shale-bands, which yielded *Climacograptus törnquisti* and *Cl. hughesi*. They dip up stream at about 40°, and about 30 feet higher *Monograptus rheidolensis* was found with *M. atavus* (F. 23). A few feet above the latter *Monograptus cyphus*, *M. revolutus*, and *Climacograptus hughesi* were obtained, in association with numerous examples of *Cl. törnquisti* (F. 23). This assemblage suggests that the beds belong to the zones of *M. rheidolensis* and *M. cyphus*, an inference confirmed by the finding of a layer of large calcareous nodules about 10 feet above the last graptolitic band. It is obvious that, as these beds occur within so short a distance of the Bryn-glâs Mudstones, a fault with a downthrow to the south-east must intervene.

The nodule-layer is succeeded by blue-black flags and shales which are highly cleaved, and the fragments of graptolites extracted from them are difficult to identify; but 25 yards up

Fig. 9.—Plan of section along Nant Fuches-wen on the scale of 18 inches to the mile.



stream from the nodules (representing a thickness of about 50 feet) the *leptotheca* band is exposed (F. 24), and, as usual, proved rich in well-preserved graptolites. These are found in full relief in

pyrite, but that mineral often shows a tendency to develop crystalline faces whereby the detailed structure of the graptolite becomes obscured, although its form is retained. The following is a list from this locality :—*Monograptus* cf. *argenteus*, *M. argutus* (c.), *M. communis* var., *M.* cf. *concinnus*, *M. gregarius*, *M. leptotheca* (v.c.), *M.* cf. *millipedia*, *M.* cf. *mirus*, *M.* cf. *triangulatus*, *Mesograptus magnus*, *Glyptograptus sinuatus*, *Climacograptus hughesi* (c.), and *Cl. scalaris* var. *normalis (?)*.

The pale greenish mudstones which succeed are somewhat monotonous in character and have yielded no fossils, but they are relieved by thin bands of dark shale from which graptolites can be obtained. The only serious gap in the section is where the footpath crosses the stream: a synclinal axis must lie hereabouts, for when the beds are next seen they dip westwards and continue so to do for about 25 yards, when they turn over suddenly in a sharp anticline which is well-exposed in the southern bank of the stream. At this point is a shaly band (F. 25), weathering to a rusty brown with a bronze lustre ; it yielded a great variety of graptolites, among which the following have been identified :—*Monograptus convolutus*, *M. harpago* (v.c.), *M. limatulus* (v.c.), *M. lobiferus*, *M. regularis*, *Orthograptus bellulus*, *Glyptograptus tamariscus*, *Climacograptus hughesi*, and *Cl. scalaris*.

Monograptus harpago is extremely abundant, occurring in matted aggregates on some of the surfaces. Exactly 25 feet above it is another shale band (F. 26) which contains abundance of graptolites, the following forms having been identified from it :—*Rastrites approximatus*, *R. capillaris*, *R. phleoides*, *Monograptus ansulosus*, *M. convolutus* var. (c.), *M. decipiens*, *M. tenuis (?)*,[1] *M. harpago*, *M. limatulus*, *M. lobiferus* (v.c.), *M.* cf. *nudus*, *M. regularis*, *Orthograptus insectiformis*, *Petalograptus palmeus*, *Cephalograptus cometa*, *Climacograptus hughesi*, and *Cl. scalaris (?)*.

This band can be followed along its strike up the steep bank on the south of the stream, and opportunity is thus afforded of seeing the same band both in its weathered and in its unweathered state. The difference in the appearance of the graptolites under these different conditions is sometimes striking. A few feet above the prolific band last described is a thick band of shale, weathering deeply to a creamy white with ferruginous stains, especially along joints (F. 27). It splits into thin flags, or into exceedingly brittle papery laminæ. The graptolites are represented by impressions of the flattened polyparies, but their outlines are quite distinct.

[1] According to Miss G. L. Elles, the graptolite described in 1843 by Portlock in the 'Report on the Geology of Co. Londonderry, &c.' (p. 319 & pl. xix, figs. 7 *a*–7 *b*) as *Graptolithus tenuis* is identical with the one described in 1868 by H. A. Nicholson (Quart. Journ. Geol. Soc. vol. xxiv, p. 539 & pl. xx, ꞉. 12–15) as *Graptolites discretus*. Portlock's name has therefore priority over Nicholson's. The form which Prof. Charles Lapworth and others have referred to Portlock's *M. tenuis* comes from a much lower horizon, and agrees with the one described in this paper as *Monograptus atavus*, sp. nov. (p. 531).

Some of the fossils can be obtained in full relief in the stream-section a few feet above the last band, and the observer has therefore an opportunity of examining the same species in different modes of preservation. The graptolites identified from this band are as follows:—*Rastrites capillaris*, *Monograptus ansulosus*, *M. decipiens*, *M. involutus*, *M. lobiferus*, *M. regularis* (c.), *M. sedgwicki* (v.c.), *M. tenuis* (v.c.), *Glyptograptus serratus* var. *barbatus*, *Gl. tamariscus* var. *incertus*, *Petalograptus palmeus*, and *Climacograptus hughesi* (c.). *Monograptus tenuis* appears to be confined to the upper part, where it occurs in extraordinary abundance.

If now we enter the old quarry on the south side of the stream, we find yet another and higher graptolitic band of dark-blue shales of a fine smooth texture, showing faint bedding-stripes of a slightly paler colour (F. 28). It passes gradually both above and below into thickly-bedded blue flags, and consequently its limits are indefinite. The graptolites, which are most abundant in a layer an inch or two thick near the centre of the band, are preserved in full relief in brown limonite and are exceedingly perfect, the specimens of *Monograptus sedgwicki* from this locality being among the most beautiful fossils in the district. It is associated with the following species:—*M. ansulosus*, *M. convolutus* var., *M. crenularis (?)*, *M. decipiens*, *M.* cf. *involutus* (c.), *M. jaculum (?)*, *M.* cf. *nudus* (c.), *M.* cf. *runcinatus*, *M. sedgwicki* (v.c.), *Orthograptus cyperoides*, and *Climacograptus hughesi* (v.c.).[1] A specimen of *Rastrites maximus* was collected from here by Mr. D. C. Evans, F.G.S., of St. Clears; and another, almost certainly referable to this species, by Mr. John Pringle and myself. They occurred but a few inches above the rich graptolitic band.

The succeeding blue flags, which were worked in the quarry, yielded only a few specimens of *Monograptus sedgwicki*, preserved in very low relief in a dark substance of chitinous appearance.

On the east side of the quarry several thin beds of tough grit with dark laminæ are interbedded with pale greenish mudstones (F. 29). From the grit-beds were obtained a large number of graptolites, among which the following species were identified:—*Monograptus becki*, *M. gemmatus (?)*, *M. nodifer (?)*, *M. nudus* var. *variabilis*, *M. runcinatus*, *M. sedgwicki (?)*, *M. turriculatus* (v.c.), and many fragments of dendroid graptolites.

This fauna was a surprise to me, as most of the forms are distinct from those of any of the underlying beds. The distance between these grits and the graptolitic band on the other side of the quarry is only 90 feet: yet, with the possible exception of *Monograptus*

[1] Miss G. L. Elles believes that the form referred here to *Monograptus sedgwicki* is one to which Barrande has given the name *Graptolithus halli*; also that the form referred to *Climacograptus hughesi* is probably the same as the one described by Dr. H. Lapworth under the name of *Climacograptus extremus*. The specimens agree, however, with *Cl. hughesi* in all essential characters, while they depart widely from the description of *Cl. extremus*. Further, I have been unable to satisfy myself that the first-named form is specifically distinct from *Monograptus sedgwicki*.

sedgwicki, not a single species is common, although the form referred to *M. runcinatus* in the lower band is certainly allied to the higher form; the palæontological break seems complete. This is the more surprising, as the succession revealed in the quarry and in the bank of the stream below shows a gradual lithological transition from one set of beds to the other. The gritty material appears at first as thin stripes in the massive flags; these increase in thickness at the expense of the muddy sediment, until they reach about 3 inches, the intervening mudstones being then of about the same thickness. In view, however, of the palæontological evidence, I have decided to separate off the strata with *Monograptus turriculatus* from the underlying beds, and to include them in a new and higher group.

(*b*) Nant Meirch (see fig. 10, p. 498).—At the mouth of the ravine which this stream has cut through the pale mudstone-group, the Castell Fault is exposed in section. On its north-west or upthrow side, a few feet of dark-blue shales with thin siliceous flags yielded *Monograptus atavus* and *Climacograptus törnquisti* (F. 30): this, taken in conjunction with the lithological character of the beds and the mode of preservation of the graptolites, suggests that they belong to the upper part of the *atavus*-zone, Crushed against the fault on the downthrow side is a band of dark, fissile, almost papery shales weathering to an ashen white (F. 31). The same band is visible also in an old leat on the opposite side of the ravine, where it is sharply folded two or three times. The graptolites obtained from it identify it as one of the *triangulatus*-bands of the Rheidol Gorge. At this point the throw of the Castell Fault is therefore 80 to 100 yards. The graptolites were *Monograptus atavus*, *M.* cf. *difformis* (v.c.), *M. revolutus*, *M. triangulatus*, *Climacograptus rectangularis*, and *Cl. törnquisti*.

The shale-band is succeeded by blue mudstones of a rather pale colour, and 25 to 30 feet above it is a band of dark-blue mudstones with a pale-green flag in the centre (F. 32). The following graptolites collected from it prove it to be the *leptotheca*-band; *Monograptus* cf. *argenteus*, *M. gregarius*, *M. leptotheca*, *M.* cf. *triangulatus*, *Glyptograptus sinuatus*, and *Climacograptus hughesi*.

The remainder of the section up to the head of the ravine shows a succession of bluish-green flags, with frequent bands of dark-blue iron-stained shales from most of which graptolites were obtained. The best exposures are along two water-leats—one about midway up the sides of the ravine and the other near the top. These are indicated by fringed lines in the sketch-plan (fig. 10).

As this is the only section known to me which exposes the whole of the Castell Group, I tabulate it here in full. It is possible, however, that a certain amount of concealed faulting may affect some of the thicknesses in the lower part, although it cannot have

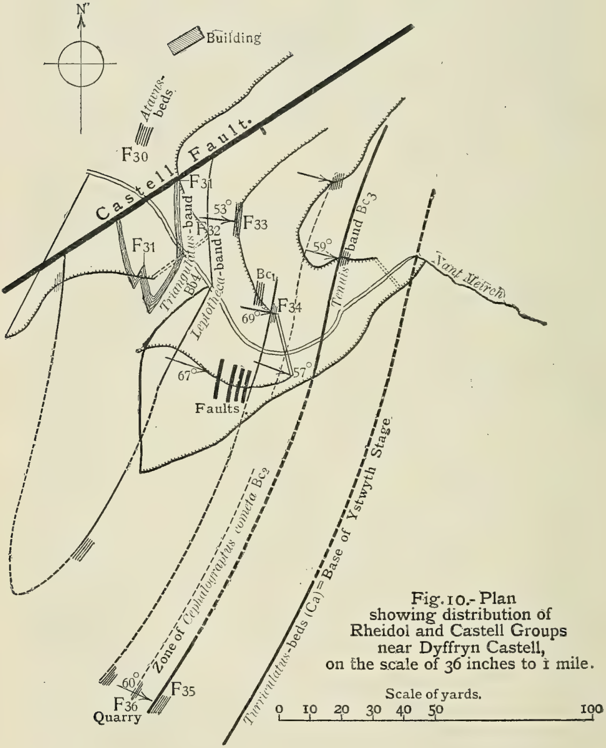


Fig. 10.- Plan showing distribution of Rheidol and Castell Groups near Dyffryn Castell, on the scale of 36 inches to 1 mile.

much influence, as the total thickness of the group does not differ materially from that calculated elsewhere.

The section is as follows:—

		Approximate thickness in feet.
(15)	Smooth blue flags, with thin black-banded grits at the top.	
(14)	Dark-blue smooth flags	3
(13)	Smooth blue flags	10
(12)	Soft shales, weathering deeply in rusty-yellow colours...	8
(11)	Smooth blue flags	20
(10)	Shales, weathering to a deep rusty brown	6
(9)	Smooth blue flags, with a shale-band about 30 feet up...	55
(8)	Bronze-weathering shales	2
(7)	Pale-blue flaggy mudstones	20
(6)	Ironstained shale-band	1
(5)	Pale-blue flaggy mudstones	25
(4)	Shales, weathering to a deep rusty brown with a bronzy lustre	4
(3)	Greenish-blue flaggy mudstones, somewhat striped with sandy layers	8
(2)	Shale band	2
(1)	Mudstones like No. 3	15
	Leptotheca band.	

In band No. 2 I found but a single specimen of *Monograptus convolutus*; in No. 4 (F. 33) that species occurred abundantly, together with *M. ansulosus, M. limatulus, M. lobiferus (?)*, and *Climacograptus* sp. In No. 6, I could find no graptolites, but No. 8 yielded several species, among which the following were identified:—*Rastrites hybridus, Monograptus ansulosus, M. decipiens, M. limatulus, M. lobiferus, M. regularis, Climacograptus hughesi*, and *Cl. törnquisti*, the last-named being exceedingly abundant.

The shaly band No. 10 is highly cleaved, and the only species that I could identify were *Monograptus tenuis* (which occurred in profusion) and *Climacograptus hughesi.*

No. 12 yielded *Monograptus decipiens, Climacograptus hughesi*, and a few others, while from No. 14 I obtained only *Monograptus sedgwicki.*

Thus, in a vertical distance of 130 feet, one passes from the base of the pale mudstone group to the characteristic band with *Monograptus tenuis*, which ushers in the zone of *M. sedgwicki.* The most conspicuous fossil in the lower part is *Monograptus convolutus*, and those beds may, therefore, be referred to that zone.

In this section I was unable to obtain fossils from the shales and black-banded grits which commence near the waterfall at the head of the ravine; but, on following them southwards along their strike for about 200 yards, the grit débris at the foot of a small crag yielded *Monograptus becki, M. nudus, M. runcinatus, M. turriculatus*, and fragments of dendroid graptolites, an assemblage agreeing closely with that from the Fuches-wen quarry.

A few yards down the slope is an old quarry in massive flags, which are some distance below the black-banded grits. Forming the top of the quarry (F. 35) are rusty ironstained shales about 6 feet thick, which are crowded in the lower part with *Monograptus tenuis.* They are underlain by about 20 feet of smooth

blue flags which pass gradually downwards into smooth shales (F. 36) with a profusion of graptolites, mainly of the following species :—*Rastrites hybridus* (c.), *Monograptus convolutus* var. (v.c.), *M. decipiens*, *M. lobiferus*, *M. regularis*, *Petalograptus* sp., and *Climacograptus hughesi* (v.c.). This fauna indicates a high horizon in the pale mudstone-group; and, from the abundance of a characteristic variety of *Monograptus convolutus* and of *Rastrites hybridus*, it may be correlated with the band containing *Cephalograptus cometa* in the Nant Fuches-wen section, and with a remarkable band in the Fagwr-fawr quarry described below. The horizon of the last-mentioned band is, therefore, fixed with some certainty at about 20 feet below the *Monograptus tenuis* horizon.

This shale-band is separated, by about 18 feet of greenish-blue flags with sandy seams, from a band of rusty shales which were too much cleaved to yield recognizable fossils. Some distance down the slope is a small exposure of ferruginous black shales: they yielded the following species indicative of the *leptotheca* band :—*Monograptus cygneus*, *M. gregarius (?)*, *M. leptotheca*, *M.* cf. *millipedia*, *M.* cf. *triangulatus*, *Mesograptus magnus (?)*, *Climacograptus hughesi*, and *Cl. törnquisti*.

The band in the quarry with *M. convolutus* var. was not recognized with certainty in the ravine-section, although it is probably the one that occurs in the centre of the blue flags (No. 9). Its fauna is so characteristic, that it may well be separated off from the lower part of the blue mudstone group which contains the typical form of *Monograptus convolutus*. It may be called the zone of *Cephalograptus cometa*, since that fossil has been frequently found in this band, and at no other horizon in the district.

Near Fagwr-fawr Farm, about half a mile north-east of Nant Meirch, the Castell Fault is seen in section in a ravine, and thence it strikes obliquely up the steep hillside, where its course can be traced by projecting bosses of fault-rock and vein-quartz. About half a mile north-east of the farm is a discarded quarry in thickly-bedded blue flags, intercalated with which are two shaly graptolitic bands. The beds strike due north with a vertical dip, and a total thickness of about 75 feet is exposed in the quarry itself and in an entrance to it cut through the solid rock on its west side. The complete section is tabulated here, for the sake of comparison with those of Nant Meirch and Nant Fuches-wen :—

	Thickness in feet.
(6) Ironstained shales; only débris seen.	
(5) Blue compact flags, passing up into pale greenish flags, about	25
(4) Flaggy smooth graptolitic shales, passing down into very soft black shales weathering in pale yellow colours, about	5
(3) Blue and greenish flags striped with sandy seams; these were worked in the quarry	24
(2) Blue, fissile, ferruginous, graptolitic shales weathering ashen white, about	3
(1) Blue flags with irregular gritty bands, seen to about	18

The shaly band No. 2 forms the west side of the quarry (F. 37), and is much weathered and broken up into thin slabs; the chief forms collected from it were:—*Rastrites approximatus*, *R. capillaris*, *R. hybridus*, *Monograptus ansulosus*, *M. convolutus* (v.c.), *M. tenuis (?)*, *M. harpago*, *M. limatulus*, *M. lobiferus* (c.), *M. regularis*, *Glyptograptus tamariscus*, *Climacograptus hughesi*, and *Cl. scalaris (?)*.

This assemblage of species indicates very clearly a high horizon in the zone of *Monograptus convolutus*. The remarkable band No. 4, which forms the east side of the quarry (F. 38), yielded in the lower part a large number of species in beautiful preservation in full and half relief. Owing probably to the local coincidence of the cleavage with the bedding, the thin band of shales in which the fossils occur can be removed in large slabs, one or both surfaces of which not uncommonly carry half-a-dozen or more species of graptolites. Such slabs, however, are not so easily procurable now as formerly, for the fossiliferous band is only a few inches thick, and a very large number of specimens have been collected from it. The assemblage of species from it is very characteristic:—*Retiolites (Gladiograptus) perlatus*, *Rastrites approximatus* var., *R. hybridus* (v.c.), *R. phleoides*, *Monograptus ansulosus*, *M. clingani*, *M. convolutus* var. (v.c.), *M. decipiens*, *M. harpago*, *M.* cf. *involutus* (c.), *M. limatulus*, *M. lobiferus* (c.), *M.* cf. *nudus*, *M. regularis* (v.c.), *M. tenuis (?)*, *Glyptograptus tamariscus* and var., *Petalograptus minor* and cf. *minor*, *P. palmeus* and var. *latus*, *Cephalograptus cometa*, *Climacograptus hughesi*, *Cl. scalaris*, and other species not yet determined.

The presence of the restricted species *Cephalograptus cometa* in this band is important, in allowing of its comparison with distant areas. The ironstained shales which occur about 25 feet above the band are lithologically similar to those of the *Monograptus-tenuis* band, but from the limited amount of material available I was not able to obtain that species.

Although the beds in the quarry are vertical, there is no question as to the band on the east side being higher than that on the west: for, on the slope to the west of the quarry, the black shales of the *Monograptus-communis* zone are exposed.

(*c*) Slope south of Eisteddfa Gurig.—The only remaining section east of Pont Erwyd to which I need refer is that along the steep slope south of Eisteddfa Gurig. It forms the natural continuation of Section III described on p. 478, wherein it was mentioned that the black shale group was followed by pale mudstones and flags. In one place, at the base of these mudstones, a few inches of a shale band are exposed, and yielded *Monograptus gregarius* and *M.* cf. *millipedia*, the latter not having been observed outside the *leptotheca* band, while the former occurs commonly in that band.

On account of the exposed position of the overlying rocks, they

are considerably weathered and the divisional planes of bedding and cleavage have been picked out, which gives to the whole group a more shaly aspect than it exhibits in the stream-sections. The softer beds crumble away, forming a shaly scree; while the harder bands stand out as ledges, by means of which an individual band can be followed easily by the eye for a considerable distance along the face of the scarp, thus enabling the investigator to supplement deficiencies in one part of the slope by observations in another part some distance away. It is unnecessary, however, to describe this section in detail. In a shale band about 35 feet above the base (F. 39) *Monograptus convolutus* was obtained, together with the peculiar *Rastrites phleoides*, *Monograptus decipiens*, *M. limatulus*, *M. lobiferus*, and *M. regularis*, an assemblage clearly indicative of the *Monograptus-convolutus* zone. The succeeding alternations of mudstones and shales did not yield many graptolites, but lithologically they recall the zones of *Cephalograptus cometa* and *M. sedgwicki*. A short distance beyond the brow of the escarpment, some pale greenish mudstones with gritty bands form a low ridge: although no fossils were obtained from them, it is almost certain that they belong to the group with *Monograptus turriculatus* and its associates.

Rheidol Gorge.—As stated on pp. 488 *et seqq.*, the Rheidol Group is followed south of Bryn-chwîth by pale mudstones and flags. At the point where they make their appearance the gorge becomes impassable, but the beds can be examined on the steep hillside to the west. About 200 yards to the south the gorge is accessible once more, but the best sections are in the old leat above, where the pale mudstones contain shaly graptolitic beds. On account of the numerous sharp folds into which the strata are thrown, no great thickness is exposed.

The shaly portions yielded the characteristic *Monograptus convolutus* and *M. lobiferus* in some abundance, together with various other poorly preserved graptolites. The abundance of *M. convolutus* in these beds suggests comparison with the lower part of the Castell Group, as displayed in the Castell Valley and elsewhere, which agrees with their stratigraphical position immediately above the *leptotheca* band.

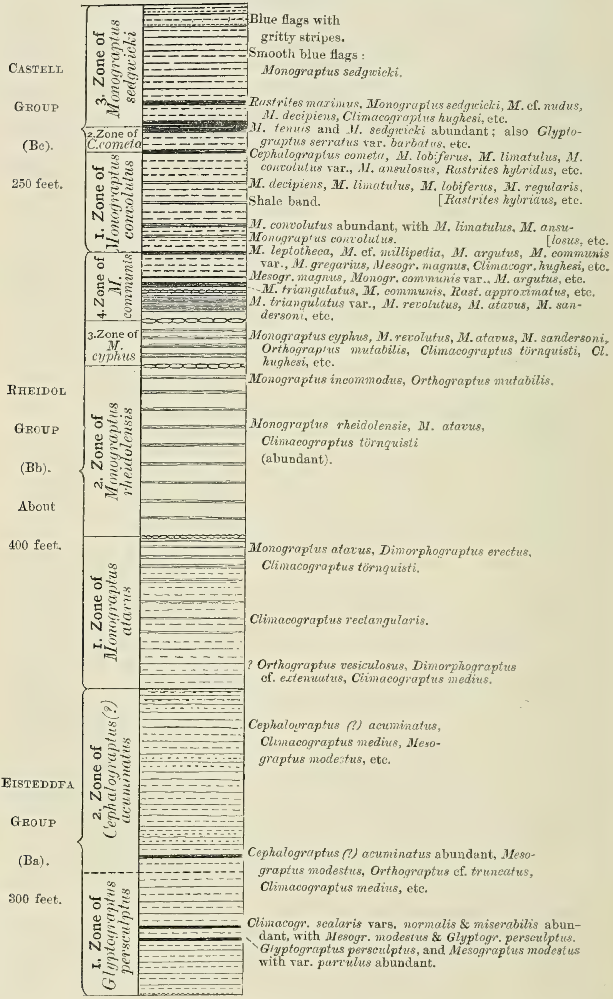
In this part of its course the Rheidol follows the line of the Castell Fault, which is visible in places in the bed of the river; but about 300 yards north of the Parson's Bridge it turns suddenly southwards out of the fault. The strata below the bend dip at about 45° down the river, and consist of thickly-bedded blue mudstones with a considerable proportion of gritty material which, on weathering, imparts to the whole group the superficial appearance of massive grits. For this reason, I was for a considerable time in doubt as to the position of these beds in the sequence, upon which depends the throw of the Castell Fault at this point. There are some shaly bands among the harder beds, but they are so much cleaved that it was only after prolonged search that they yielded

graptolites sufficiently good to fix the age of the group thereby. One of these bands (F. 40), below a disused mine-building 60 yards south of the bend in the river, yielded :—*Monograptus convolutus*, *M. decipiens (?)*, *M. lobiferus*, and *Climacograptus scalaris (?)*. The presence of the first is sufficient to assign fairly close limits to the band. Another highly-cleaved bed of ferruginous shales forms the base of a bluff about 70 yards down the river, and is separated from the foregoing by about 80 feet of strata. It strikes across the river and up the eastern bank, where the beds are less cleaved, and yielded the following species (F. 41) :—*Monograptus decipiens*, *M. harpago*, *M.* cf. *involutus*, *M. sedgwicki*, *Orthograptus cyperoides*, and *Climacograptus hughesi*. It may, therefore, be referred to the zone of *M. sedgwicki*, but probably a few feet above the base of that zone. The hard gritty mudstones higher up the river must consequently be low down in the Castell Group; and the throw of the Castell Fault at this point is probably not much more than 30 yards, being, in fact, but little greater than the thickness of the zone of *Monograptus communis*.

The strata succeeding the higher graptolitic band dip down the river as far as the Parson's Bridge. At this point the river-channel becomes exceedingly narrow, being in many places not more than 2 or 3 yards wide, and the bed has been worn into large and deep potholes, which figure in most of the local guide-books. Below the bridge the rocks are sharply folded into fairly symmetrical anticlines and synclines with a low southerly pitch; and it is interesting to observe the manner in which the river-channel follows one of these structural lines for a considerable distance, then, suddenly breaking out of it, takes up another a few yards away. For over 300 yards south of the bridge the channel is cut along the crest of an anticline; it then leaves the anticline abruptly, and, after several small folds have been crossed, a well-marked syncline exactly defines the course of the river for the next 200 yards. Below this point it sways now to one side, now to the other, of the synclinal axis, but for nearly half a mile does not deviate therefrom by more than a few yards. Then once more breaking away at right angles, the river-channel falls into the line of an anticline and maintains this position for a long distance to the south. It follows, from the relation of the channel to the folds, that no great thickness of rock is exposed along the river for at least a mile below Parson's Bridge. The beds consist of flags and shales, with some thin grits. In several places the shales yielded graptolites, among which the following have been identified :—*Monograptus becki*, *M. involutus (?)*, *M. jaculum (?)*, *M. nodifer (?)*, *M. nudus* var. *variabilis* (v.c.), *M. runcinatus* (c.), *M. sedgwicki*, *M. turriculatus*, *Glyptograptus serratus (?)*, *Petalograptus palmeus*, and *Climacograptus scalaris*.

This fauna agrees essentially with that of the beds following the *sedgwicki* zone in other parts of the district, and therefore must be included with them in a higher group; but it is impossible in this

Fig. 11.—*Vertical section of the Pont Erwyd Stage, showing the distribution of the more important graptolites.*



[Scale : 1 inch = 150 feet.]

section to draw a hard-and-fast line on lithological grounds between these strata and the top of the *sedgwicki* zone. The transition must take place somewhere in the neighbourhood of the Parson's Bridge, and it is possible that the thin grits which make their appearance just below the bridge mark the oncoming of the newer group.

It is unnecessary to describe in detail the other sections of the Castell Group. It will suffice to refer briefly to the one on the hillside south of Bryn-brâs. The *convolutus* beds are somewhat gritty in places, in this respect resembling those in the gorge south of the Castell Fault. They are followed by 110 to 120 feet of smooth blue flags, which yielded (F. 42) *Monograptus clingani*, *M. convolutus (?)*, *M. crenularis* var. *a* (Lapw.), *M. jaculum*, *M. sedgwicki*, and *Acanthograptus ramosus (?)* near the base; while thin grits appear in the upper part, forming a transition to the group of pale mudstones and shales with thin black-banded grits which furnished the *turriculatus* fauna, that form being found in considerable numbers with *Monograptus becki*, *M. runcinatus*, and dendroid graptolites.

I need only refer to one other fossiliferous locality in the western belt of the Pont Erwyd Beds, which runs northwards from the village along the Rheidol Valley. This is found at the top of the old quarry by the stream north-east of Gwenffrwd-uchaf Farm, where the *leptotheca* band was mentioned on p. 492. That band is followed by 43 feet of smooth, thickly-bedded, greenish-blue flags, which were worked in the quarry; they pass up gradually into a band of deeply-weathering rusty shales (F. 43), which yielded the following assemblage characteristic of the *M. convolutus* zone:—*Rastrites approximatus*, *R. capillaris*, *R. hybridus (?)*, *R. peregrinus*, *Monograptus ansulosus*, *M. concinnus (?)*, *M. convolutus* (v.c.), *M. decipiens*, *M. harpago (?)*, *M.* cf. *involutus*, *M. limatulus*, *M. lobiferus*, *M.* cf. *nudus*, *M. regularis*, *M. tenuis (?)*, *Glyptograptus tamariscus*, *Climacograptus hughesi*, and *Cl. scalaris*.

This band forms the top of the quarry, and is followed by pale greenish shales and mudstones with thin black-banded grits; all the beds weather to a pale lemon-colour, and are not unlike the *M.-turriculatus* beds. A thickness of 80 to 100 feet is exposed; but I could detect no shale-bands among them, and I am unable to say to what part of the succession they pertain.

On p. 504 is a vertical section through the Pont Erwyd Stage, showing the distribution of the graptolitic horizons and the lithological character of the strata (fig. 11).

The Fauna of the Pont Erwyd Stage.

The fauna of the Pont Erwyd Stage consists almost entirely of graptolites of the families Diplograptidæ and Monograptidæ.

The Eisteddfa Group at the base contains Diplograptidæ exclusively; the species *Mesograptus modestus* and its varieties, as also

several forms related to *Climacograptus scalaris,* being the most abundant. In the lower part of the Rheidol Group, also, Diplograptidæ are the only forms, represented chiefly by *Climacograptus scalaris* var. *normalis*, *Cl. medius*, and *Cl. rectangularis*; but about 150 feet up the first *Monograptus* (*M. atavus*) makes its appearance, in company with *Dimorphograptus* and *Climacograptus törnquisti. M. atavus* has, however, a considerable vertical range above the horizon at which it first appears, although it is there accompanied by other forms of *Monograptus* which are not represented at lower horizons.

The zone of *Monograptus rheidolensis* is especially characterized by the abundance of *Climacograptus törnquisti*, which is more abundant than the zone-form itself, but is not confined to this zone. In this and the succeeding zone of *M. cyphus*, the well-marked species *Orthograptus mutabilis* is extremely abundant at certain horizons.

It is a striking fact that in these zones, and even in the succeeding zone of *Monograptus communis*, there is a total absence of straight rigid *Monograpti*; every species is more or less curved. In the zone of *M. communis,* species with triangular thecæ first make their appearance; they become important in the Castell Group. Also, towards the middle of the zone, the genus *Rastrites* appears for the first time in the ascending sequence, and is represented by several forms. The fauna of the *leptotheca* band is interesting as a connecting link between those of the Rheidol and the Castell Groups; at that horizon species of *Monograptus* carrying thecæ with well-developed lobes are fairly common, foreshadowing the dominant types of the succeeding group.

In the Castell Group coiled forms with triangular thecæ (*M. convolutus*, *M. decipiens*, *M.* cf. *involutus*, etc.), and more or less straight forms having strongly lobed thecæ (*M. lobiferus*, *M. harpago*, etc.), may be regarded as the characteristic types; but they are accompanied by straight rigid *Monograpti* with simple cells (*M. regularis*, *M.* cf. *nudus*, etc.). In the higher beds, forms having more complicated thecæ (*M.* cf. *runcinatus*, *M. sedgwicki*, etc.) occur, representing early mutations of forms which characterize more especially the overlying Ystwyth Stage. Thus it is possible, by paying attention to the general types of species, to determine the main groups of the Stage, even though the forms may not be specifically identifiable. This consideration is likely to be of importance in mapping certain parts of the Central Welsh region, where intense cleavage will probably render the precise determination of the fossils a matter of considerable difficulty.

C. The Ystwyth Stage.

The highest stage in the district is of some importance, on account of the large area which it occupies. This is due, not only to the considerable thickness of the rocks included within it, but also to

the nature of the folding which they have suffered. Thrown as they are into a rapid succession of rather shallow folds with a low southerly pitch, these rocks occupy the surface of the country for many square miles, and it becomes a matter of some difficulty to ascertain the relations of the various rock-types which this stage comprises.

In dealing with the Plynlimon and Pont Erwyd Stages, we saw that the outcrops of the different groups were arranged in a series of broad V's pointing southwards, so that in a general sense newer rocks succeed the older in traverses from north-west to south-east, from north-east to south-west, or from north to south; and one may reasonably assume that a similar order prevails among the rocks of the highest stage. In order, therefore, to gain an acquaintance with the disposition and characters of the later rocks, the results of two or three traverses across the hilly district lying east of the Rheidol Valley will be described.

The first traverse (fig. 12, p. 508) was taken from the main road about half a mile north of Yspytty Cynfyn, in an easterly direction to the head of the Myherin Valley. On the east side of the road is a steep grassy and gorse-covered slope, capped by a scarp of bare rock dipping eastwards at 45°. The débris from the scarp accumulates at its foot, and also tails down the slope, reaching in places nearly to the road. The strata consist of alternations of pale-grey flags, and numerous 1 to 3-inch bands of grit with curved black laminæ, in this respect resembling the basal beds of the Ystwyth Stage in the Castell Valley. It is possible, however, that the rocks under consideration lie a short distance above the base. The débris of the grits (F. 44) yielded *Monograptus becki*, *M.* cf. *dextrorsus*, *M. runcinatus*, and *M.* sp. with a *tenuis*-like curve, together with *Dictyonema*.

In addition to the above, Mr. John Pringle and I discovered several specimens of what have been pronounced by Dr. G. J. Hinde, F.R.S., to be the jaws of annelids. He reports as follows:—

'The specimens from the Tarannon of Cardiganshire . . . are the jaws of Annelids of the same character as those which I worked at in 1879 and subsequently from Canada and the Isle of Gotland, and also from the Wenlock and Ludlow of the West of England; see Quart. Journ. Geol. Soc. vol. xxxv (1879) p. 370, pls. xviii–xx & vol. xxxvi (1880) p. 368, pl. xiv; also Bihang till K. Svenska Vet.-Akad. Handl. vol. vii, No. 5 (1882) p. 3 & pls. i–iii.

'I can distinguish two forms. . . . . . In one there is a prominent anterior hook, followed by a series of small pointed denticles extending along the upper margin of the jaw. In the second one there is a stout hook, followed, after an interval, by three minute pointed denticles and then by a series of flat-topped denticles. They are, in matters of detail, different from any of the forms described in the papers referred to above.'

West of the road rocks of a like lithological type are exposed, dipping westwards, and, judging by the form of the ground, I am disposed to think that an anticlinal axis must bring up a considerable area of the Castell Group on the south side of the Castell Fault.

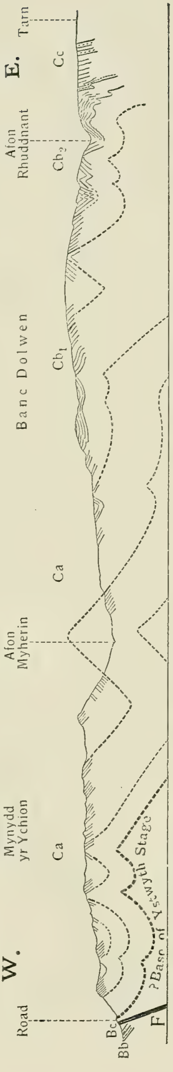


Fig. 12.—*Section from the main road, 800 yards north of Yspytty Cynfyn, to Llyn Rhuddnant, showing the rock-sequence in the Ystwyth Stage and the general structure, on the scale of 2 inches to the mile. (Section No. VI on the Map, Pl. XXIV.)*

[Bb = Rheidol Group. Bc = Castell Group. Ca = Devil's Bridge Group. Cb = Myherin Group. Cb_1 = Dolwen Mudstones. Cb_2 = Blaen Myherin Mudstones. Cc = Rhuddnant Group. F = Castell Fault.]

After reaching the edge of the scarp dominating the road the ground rises gradually eastwards from 1000 to about 1500 feet. The surface presents a succession of long rocky ridges with intervening hollows, which are usually covered with peat. These features are due to the folding of the rocks, their direction being that of the anticlinal and synclinal axes. There is no definite correspondence between the position of the axes and the ridges or hollows, for in some cases an anticlinal axis occupies the crest and a synclinal axis the hollow ; but more often these relations are reversed, while in other cases an axis runs along one of the bounding slopes. Also the hollows not unfrequently coincide with a belt of compression, where two or three sharp folds rapidly succeed one another. All that can safely be said is that the undulation of the ground is an indication of folding in the rocks, and that the strike of the ridges and hollows defines the direction of the folding axes.

The rocks are monotonous in the extreme, in their regular alternation of pale greenish flags with thin gritty bands. On this moorland tract any soft shale-beds that they may contain are masked by superficial accumulations, and consequently there is little chance of obtaining fossils.

On the steep slope from Banc Tymawr into the Myherin Valley exposures are more continuous, and bands of dark ironstained shale with

graptolites appear. Fossils were collected from several places along the road down into the valley from Yspytty Cynfyn, the following being identified :—*Monograptus becki*, *M. marri*, *M. nudus* var. *variabilis*, *M. resurgens*, and *M. runcinatus (?)*.

At the point where a small stream crosses the road *Rastrites linnæi*, *Monograptus exiguus*, and *M. nudus* var. *variabilis* were collected (F. 45); this is the lowest horizon at which I have found *M. exiguus*, a species which becomes so abundant in higher strata. Nearly opposite this locality the Afon Myherin turns almost at right angles, from an east-and-west course in the upper part to a north-and-south course. A very fair section is exposed along the steep slopes and numerous crags on both sides of the upper portion of the valley, which is nearly 2 miles long.

In the first part of the section the beds are somewhat similar to those already passed over; but the grit-bands are noticeably fewer and thinner, being often mere stripes. The intervening mudstones accordingly appear more massive: their prevailing colour is a pale greenish blue. Some poorly preserved graptolites were obtained from the north side of the valley about half a mile east of the bend: *Monograptus nudus* var. *variabilis* was the commonest form.

The rocks appear to dip eastwards at about 30° to 50° along the whole length of the valley, and this seems to point to an enormous thickness of strata. It is, however, doubtful whether the easterly dip is as persistent as it appears, for gaps frequently occur where little or no rock is exposed; and, as we have seen, such gaps usually coincide with an undulation of the strata or with a belt of compression. If, as I have reason to believe, this is a fairly general rule, it greatly reduces the thickness as calculated from the visible dip and the length of the exposures.

Despite the folding, however, the section is an ascending one towards the east, for any compression which may take place at the gaps is not sufficient to counteract the visible easterly dip. Of course, this argument would be of no value in the presence of strike-faulting; but, so far as I am aware, such faulting is rare in these rocks, and its effect may therefore be ignored. Moreover, certain changes in lithology become apparent in ascending the valley, which are consistent with the view that one is dealing with a rock-sequence. Gritty bands almost disappear, and mudstones become dominant; the colour of the rocks gradually darkens, and frequent bands of dark shale weathering in pronounced rusty-red and brown tints occur among them. Most of the shaly bands contain graptolites; but the persistent cleavage makes their extraction and subsequent identification somewhat difficult.

About halfway up the valley the Myherin is joined from the north by Nant-y-Creiau, which emerges from a gloomy ravine where some mining operations were carried on not long ago. About a quarter of a mile to the east the south side of the Myherin Valley is furrowed by a small gully exposing a section in soft, pasty, blue-hearted mudstones which are intensely cleaved. They

yielded *Monograptus resurgens* only about the middle of the section (F. 46). The beds are folded into an anticline, and are followed by a considerable thickness of hard, compact, blue mudstones. At the foot of the great crags which rise to the east of the gully I obtained the following graptolites (F. 47):—*Rastrites linnæi*, *Monograptus becki*, *M. marri*, *M. nudus*, and *M. resurgens*. This assemblage is not unlike that at the western end of the valley, and from the nature of the folding it does not seem improbable that the rocks at these two localities are nearly on the same horizon.

About a quarter of a mile to the east is another imposing line of crags, the débris from which tails for a long way down the slope. I could find no fossils *in situ*; but, by searching carefully in the débris, Dr. Herbert Lapworth and I obtained a fairly good collection, consisting of the following species (F. 48):—*Monograptus crassus*, *M.* cf. *exiguus* (v.c.),[1] *M. galaensis*, *M.* cf. *holmi*, *M. marri (?)*, *M. nudus*, *M. tortilis (?)*, and a curious large curved *Monograptus* which I could not identify specifically.

From this point to the end of the section the south side of the valley presents a succession of rocky crags, alternating with slight depressions or narrow clefts which mark the position of bands of soft shale among the more intractable mudstones. Graptolites may be obtained from all the shaly bands.

South of Blaen Myherin Farm dark-blue thickly-bedded mudstones, of a smooth soft texture and weathering in orange-yellow and vermilion tints, make their appearance; they are associated with bands of dark shale, weathering in brighter colours, which yielded graptolites in several places. A thick bed of shale which occurs in a prominent groove in the hillside due south of Blaen-Myherin Farm (F. 49) yielded *Monograptus galaensis*, *M. marri*, and a form which approaches most nearly to *M. priodon*.

Another bed about 100 feet higher (F. 50) gave *Monograptus distans*, *M. exiguus* (c.), *M. holmi*, *M. nudus*, and *M. tortilis*; while another band about the same vertical distance above it (F. 51) furnished *Monograptus exiguus*, *M. nodifer*, *M. nudus*, *M. turriculatus* (c.), and *Petalograptus palmeus* var. *tenuis*.

The section practically ends at the cart-road leading from the farm to the peat-grounds on the south, there being only a few scattered exposures of dark-blue mudstones beyond this for a considerable space

When the western edge of the moorland tract of Cefn Croes is reached, a coarse, grey, speckly felspathic grit makes its appearance rather unexpectedly, while the ground is covered in places with its débris. This rock compares better with the coarse grits of Plynlimon than with anything else in the whole succession, and therefore it is important to ascertain its relationship to the great

[1] This is probably the form mentioned by Miss E. M. R. Wood (Mrs. Shakespear) in her paper on 'The Tarannon Series of Tarannon' Quart. Journ. Geol. Soc. vol. lxii (1906) p. 679, footnote.

group of mudstones and shales which lie to the west. This is illustrated very clearly in the Rhuddnant section described below.

There is an admirable section through the upper part of the mudstone-group in the ravine of Nant-y-Crwth, east of Blaen Myherin. The rocks are soft, thickly-bedded, and of a dark-blue colour, frequently exhibiting on weathering concentric rings of orange-red and vermilion; this is a characteristic feature of these beds wherever they are well exposed. The shale-bands interbedded with the mudstones weather in somewhat brighter tints; most of the graptolites occur in them. About 150 yards east of the point where the section ends on the brow of the hill, coarse speckly grits are exposed on the moorland, and are associated with dark-blue smooth shales: among these latter are intercalated numerous greyish-white siliceous bands, from half an inch to 2 inches thick and of a fine texture. A single specimen of *Monograptus turriculatus* was found in a small exposure about 100 yards west of the grit-outcrop, and therefore not very far below it.

East of the grits lies an extensive moorland tract, traversed in a north-and-south direction by ridges and hollows. A few exposures of coarse grey grits, added to the débris of similar material lying about, suggest that such rocks may extend for a considerable distance eastwards; but, from the stratigraphical point of view, it is useless to pursue the section farther in that direction.

This traverse has shown that there is a sequence of distinct rock-types, arranged in ascending order from west to east. On the west are the pale greenish flaggy mudstones with frequent grit-bands, which extend uninterruptedly from Yspytty Cynfyn to the Myherin Valley; then follow along that valley higher strata of a somewhat similar colour, but in which the mudstone-type is dominant and the gritty bands are thin or absent. These form the greater part of the valley; but towards its upper end they become more shaly, and are distinguished also by their soft smooth texture, dark-blue colour, and their property of weathering in brightly-tinted concentric patches. Finally, on the high moorland which dominates the valley on the east there occurs a very distinct lithological type, consisting of coarse speckly grits associated with blue shales that contain greyish-white siliceous bands. The section (fig. 12, p. 508) is intended to illustrate this sequence, and to represent to a certain extent the manner in which the rocks are folded; it does not lay claim to more than approximate accuracy.

Although the strata are thrown into numerous undulations, there is no difficulty in seeing, when on the ground, that the changes described above take place in a series of considerable thickness. They cannot be explained on the assumption of repetition by folding and faulting of a small thickness of variable deposits.

The group of regularly alternating mudstones and grits forming the lower part of the stage can be recognized over a great extent

of country, both north and south of the line of section. As a rule, exposures are not good, and graptolites are difficult to find, except near the base and summit of the group. On the north they occur around the tarns called Llynoedd Ieuan, and in the precipices overlooking Cwm Ergyr; while on the south they form the hills of Erw Berfa and Ty'nllwyn, which divide the valley of the Rheidol from those of the Myherin and the Mynach.

If a traverse be made from the Rheidol Valley across the former hill, about a mile south of the previous one, the Myherin is reached where it is joined by the Rhuddnant to form Afon Mynach, on which occur the well-known falls at the Devil's Bridge. The mudstone-and-grit group is thrown into numerous undulations in which anticlines and synclines succeed one another with a certain degree of regularity, as shown by the long north-and-south ridges.

In the continuation of the section along the Rhuddnant the mudstones contain thin grit bands for a distance of nearly a mile up that valley; then they disappear quickly. The upper part of the valley offers some of the wildest scenery in the district: for more than a mile the north side is formed of bare rock, which descends almost sheer from the edge of the moorland to the bed of the stream 600 or 700 feet below. Numerous anticlines and synclines may be detected, and the course of the strata as they sweep up and down the side of the ravine can be followed very clearly. Graptolites were obtained at several places along the valley in the bands of ironstained shale which occur in the mudstones; these are of the same species as those recorded from the Myherin Valley above Nant-y-Creiau. As in that section, the mudstones become darker in ascending the sequence, and their peculiar mode of weathering in brilliant concentric rings becomes conspicuous. These changes set in about 2 miles up the valley, near the right-angled bend which the stream takes after cascading down from the moorland above; and the blue-black mudstones and shales are beautifully exposed between that point and the head of the ravine, although they are not readily accessible.

When the edge of the moorland is reached, where the stream begins to plunge into the ravine, the mudstones give place gradually to soft blue shales weathering in rusty-bronze tints. A few yards higher up stream thin greyish-white siliceous streaks make their appearance in the shales, and are seen to increase in number in ascending the section. These striped rocks are followed immediately by several feet of coarse, grey, speckly grit in rather thick beds: this sequence appears to correspond with that observed at the head of the Myherin Valley. In the section now described, however, higher strata are seen to a thickness of 400 or 500 feet; they consist, in the main, of soft, smooth, blue shales with thin gritty bands and an occasional bed of massive, coarse, speckly grit. Near the point where the stream emerges from the tarn known as Llyn Rhuddnant, a fresh lithological type makes its appearance; the blue shales there contain a series of hard, dark-blue, fine-grained grits,

in beds from 2 to 4 inches thick, which alternate regularly with about an equal thickness of shales. A few pieces of a flaggy brown rottenstone occur among the débris, but I found none *in situ*. At this point the section ends.

The shaly group with grits yielded very few fossils, although these were diligently searched for on more than one occasion. The beds at the tarn (F. 52) were found to contain *Monograptus holmi*, *M. marri*, and *M. priodon*; and, in the neighbourhood of a coarse grit about 100 yards down stream, *Monograptus marri (?)* and *M. turriculatus* were obtained.

The few scattered exposures, mainly of grit, on the moorland east of the tarn are of no value, beyond proving that the group extends for a considerable distance in that direction.

I propose to describe briefly a third traverse eastwards, commencing at Devil's Bridge and following for some distance the road to Rhayader, for the reason that an extensive suite of graptolites was obtained from the lower group of mudstones with thin grits, thus making up for a deficiency in the traverses across the hilly moorland-country on the north.

In the description of the Rheidol gorge, below Parson's Bridge, attention was called to the numerous undulations which have affected the strata; from this circumstance, and from the low pitch of the folds, it results that no great thickness of rocks intervenes between Devil's Bridge and Parson's Bridge, where the group under consideration commences. The fossils obtained from various places along this part of the gorge (see p. 503) agree closely with those extracted from the base of the group in the Castell Valley and elsewhere.

The rocks of Devil's Bridge were diligently searched by Walter Keeping, who was rewarded by the discovery of numerous forms of *Cladophora*, subsequently described by Prof. Charles Lapworth. He also obtained *Monograptus turriculatus* near the same spot. I was not successful in discovering the locality from which he obtained it, nor could I find any of the forms of *Cladophora* recorded by him from the quarry near the bridge. The rocks are of the pale-greenish mudstone type, with frequent laminated grits up to 2 or 3 inches thick; they extend, with but little variation, for about 2 miles along the Rhayader road.

Graptolites were found by the side of the road due south of Bodcoll Mill, about two thirds of a mile from the Hafod Arms Hotel (F. 53). They comprised the following species:—*Monograptus becki (?)*, *M. densus*, *M. marri (?)*, *M. nodifer*, *M. nudus* var. *variabilis (?)*, and *M. turriculatus*.

About 500 yards up the road is a quarry in tough, flaggy, laminated grits, which are interbedded with thin bands of smooth blue shales (F. 54). One of these yielded to Mr. John Pringle and myself a large number of excellently-preserved graptolites of the following species:—*Monograptus becki* (c.), *M. crassus*, *M.* cf.

involutus (c.), *M. jaculum*, *M. nodifer*, *M. nudus* var. *variabilis* (v.c.) and another variety, *M. runcinatus*, *M. turriculatus*, *Glyptograptus* cf. *tamariscus*, *Petalograptus palmeus*, *P.* (?) sp., and *Climacograptus scalaris*. The beds dip E. 25° S. at 70°, but a few yards farther west they turn over in a sharp anticline.

Between this locality and The Arch, 2 miles from Devil's Bridge, graptolites were obtained from red-stained shales at several points by the roadside. Thus, about 200 yards down the road from the Arch (F. 55), Mr. Pringle and I found *Monograptus intermedius*, *M. lobiferus* (?), *M. nodifer*, *M.* cf. *nudus*, *M. nudus* var. *variabilis* (v.c.), and *Climacograptus scalaris* (?).

Beyond The Arch, where the road begins to descend towards the valley of Nant Peiran, the rocks consist mainly of blue mudstones with occasionally a few gritty bands. Lumps of flaggy rottenstone are conspicuous among the débris for some distance on both sides of The Arch.

Near Pwll Peiran Bridge is a quarry by the roadside, in hard blue-grey, rather massive mudstones; but no fossils were discovered in them. The gritty bands disappeared somewhere between this point and The Arch.

There are very few exposures along the road to the east of this, until the steep descent towards Cwm Ystwyth School is reached, where there is a good section in smooth, dark-blue, thickly-bedded mudstones, weathering in rusty-brown shades and frequently showing concentric orange-red and vermilion stains. Bands of soft shales occur among them, but all are astonishingly contorted and so intensely cleaved that it was almost a hopeless task to search for graptolites in them. However, their marked lithological characters and mode of weathering render their identification with the blue-black mudstones at the head of the Myherin and Rhuddnant Valleys almost a certainty.

About half-a-mile along the road, just beyond the Post Office of Pentre Briwnant, is a small exposure of highly-cleaved smooth shales, which led me to expect the grit-group hereabouts. In this, however, I was disappointed; for the next exposure, less than half-a-mile to the eastward, was of blue-grey mudstones, probably below or about the base of the dark-blue mudstone-group. I followed the Ystwyth Valley for nearly a mile beyond the Cwm-Ystwyth Lead-works in the hope of seeing the grits, and perhaps of finding higher beds than are exposed in the Rhuddnant section, but only found blue-grey and dark-grey mudstones like those towards the upper part of the Myherin Valley, and therefore a considerable distance below the base of the grit-group.

The district around Pentre Briwnant is, however, extremely faulted, as is indicated by the complicated network of metalliferous veins which have been worked there for several centuries.

A better idea of the sequence in the higher part of the Ystwyth Group may be obtained by leaving the road at The Arch, and following a cart-track over the hills to the north. For about three-

quarters of a mile this track lies approximately along the strike, and not much rock is visible. Near Craig-y-Cauleth laminated gritty bands are present among the mudstones, but they disappear immediately to the east of that. By the side of the track, about one-third of a mile north-east of Craig-y-Cauleth, there is a small exposure of blue mudstone with rottenstones, some of which are crammed with crinoid-ossicles and minute brachiopods (chiefly *Orthis*). The only graptolite that I obtained was *Monograptus intermedius*. In slightly lower beds at the foot of Coed-y-Cauleth (F. 56) I found several species of graptolites:—*Monograptus crassus*, *M. marri* or *becki*, *M. nudus (?)*, and *M. resurgens*. This assemblage indicates, as compared with the Myherin Valley, a horizon near the base of, or slightly below, the blue mudstone-group, which agrees with the position independently assigned to it from stratigraphical evidence.

This group occupies a width across the strike of about 1000 yards, and is followed eastwards by the group of dark-blue mudstones and shales, the former weathering in their characteristic manner. These rocks are well exposed in the magnificent precipice of Craig-y-Ceffyl, and graptolites may be obtained from the shaly bands by the side of the cart-road which skirts the edge of the precipice (F. 57). The following species were collected there:—*Monograptus priodon (?)*, *M. turriculatus*, *Petalograptus palmeus* var. *tenuis* (c.), and *P. altissimus (?)*. The outcrop occupies a width of 400 or 500 yards, but the rocks are probably folded.

East of Craig-y-Ceffyl the mudstones are succeeded by a shaly group, and in a short distance a bed of coarse speckly grit, resting upon blue shales with greyish-white siliceous bands, may be observed by the side of the cart-track, and is exposed again at frequent intervals along the track for about 300 yards; this is due to a series of sharp folds, which cause the outcrop to zigzag rapidly, its general trend being nearly at right angles to the axes of the folds (see Map, Pl. XXIV). At the end of this space the dip becomes steady towards the east, and the grit strikes northwards without much interruption to Nant Rhuddnant.

This sharply-folded belt is probably the one so clearly exhibited in the dark-blue mudstones near the head of the ravine of the Rhuddnant; for, if the axes of those folds be prolonged southwards, they pass well to the east of Craig-y-Ceffyl.

The grit-group strikes steadily southwards from this locality for about a mile, beyond which I have not followed it. When last seen, it was striking along the steep slope of Llethr Brîth and Penlan-fawr towards Pentre Briwnant; but, as has been mentioned already, it does not make its appearance along the road at Cwm Ystwyth. A good deal of detailed work might be done on that complicated mining district, which would take up more time than I had at my disposal.

Supplementary exposure.

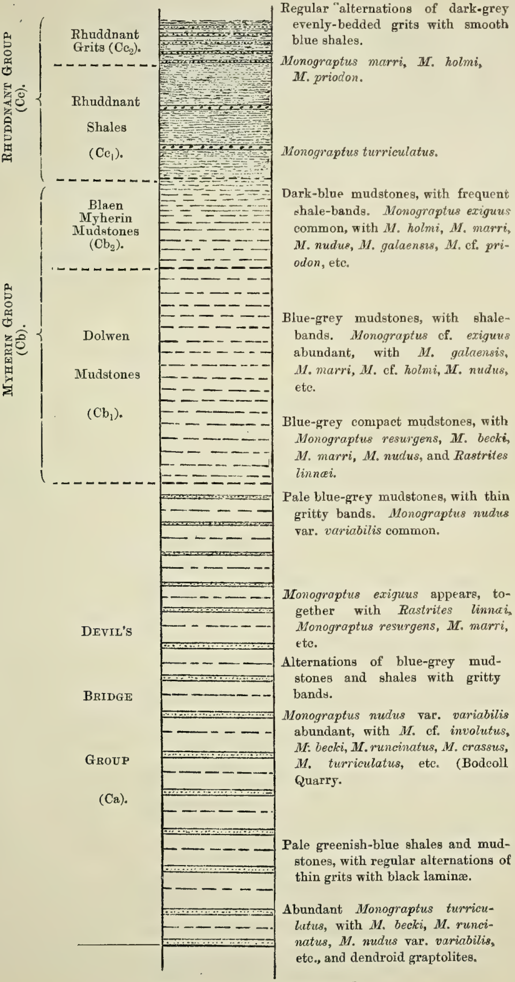
Half-a-mile south of Craig-y-Ceffyl is a good section in the blue-black mudstones and overlying shales, in the small stream of Nant Hylles. About 50 yards up stream from an old sheepfold, the mudstones contain a thin sandy shale-band which weathers to a buff colour (F. 58); it yielded many graptolites, mostly in a fragmentary condition, among which the following species were identified:—*Monograptus exiguus* (c.), *M. galaensis*, *M. holmi* (v.c.), *M.* cf. *holmi* approaching *priodon*, *M. proteus*, and *M. turriculatus* (v.c.).

The result of the traverses across the southern part of the district has been to demonstrate the existence within the Ystwyth Stage of three distinct rock-groups, which always follow one another in the same order from west to east, namely:—(i) The group of mudstones with regular alternations of thin grits, to which the name of Devil's Bridge Group is given; (ii) a group of mudstones almost devoid of grits, but containing numerous shale bands, especially in the upper part: for this the name Myherin Group is suggested; and (iii) a shale group, in which occur bands of coarse speckly grit and evenly-bedded, dark, gritty flags: the name of Rhuddnant Group seems appropriate for this, as it is not so well displayed anywhere else within the limits of the district. Again, within the Myherin Group two subgroups can be readily distinguished:—(*a*) a lower, characterized by the pale-blue or grey colour of the mudstones and the comparative rarity of shaly bands: from their fine development on Banc Dolwen, south of the Afon Myherin, they may be distinguished as the Dolwen Mudstones; (*b*) the upper is easily recognized by the dark-blue colour and almost glossy character of the rocks, and by their peculiar property of weathering in concentric rings of a bright orange-red or vermilion: shaly bands are relatively more frequent and thicker than in the lower subgroup, and I can suggest no better appellation for them than that of Blaen Myherin Mudstones, after the name of the farm at the head of the valley.

That the order of these groups is one of ascending sequence from west to east is shown by the magnificent sections along the Myherin and Rhuddnant Valleys, where, despite numerous undulations, the predominant effect of the easterly dip is very clear. This is also only what might be expected from the disposition of the lower strata of the district; for it has been shown, when dealing with those groups, that, in any traverse from west to east or from north-west to south-east, we pass (on the whole) from older to younger strata: that is, the sequence is an ascending one in that direction.

Fig. 13 (p. 517) illustrates the general sequence within the stage, and the graptolites which characterize certain horizons.

Fig. 13.—*Vertical section through the Ystwyth Stage, showing the lithological and palæontological succession.*



[Scale: 1 inch = 500 feet.]

The Fauna of the Ystwyth Stage.

With the exception of the annelidan jaws mentioned on p. 507 and a few annelid-tracks, the fauna is entirely graptolitic. The Stage as a whole, or so much of it as is represented in the area, is characterized by the occurrence of certain species, or groups of allied species, principally of *Monograptus*; but a comparison of the forms from the higher with those from the lower beds shows that considerable changes have taken place in the interval (see vertical section, fig. 13, p. 517). Such changes are, however, gradual, the central parts of the Stage having a fauna clearly intermediate between that of the lower and that of the upper portions.

Monograptus turriculatus, which appears suddenly in great numbers in the lowest beds of the Stage, seems to have survived throughout, since it is also found in almost the highest beds; and in the upper part of the Blaen Myherin Mudstones it is one of the commonest forms. With the exception, however, of a single specimen from Bodcoll Quarry, about the middle of the Devil's-Bridge Group, the species has not been discovered in the intermediate beds.

A number of forms which may be grouped around *Monograptus nudus* occur in the Ystwyth Stage. *M. nudus* var. *variabilis* is one of the most abundant and characteristic forms in the Devil's-Bridge Group, and appears to be confined to it; the other varieties which accompany it are smaller and narrower than the typical form as figured by Prof. Charles Lapworth, which only becomes abundant in the Myherin Group.

Another interesting group is typified by the straight lobiferids, *Monograptus marri*, *M. holmi*, and *M. priodon*, which are common in the Myherin and Rhuddnant Groups, although the first form may occur in the upper part of the Devil's Bridge Group. In the Blaen-Myherin Mudstones and higher beds, *M. holmi* is the most abundant graptolite, and is generally accompanied by forms which must be referred to the early types of *M. priodon*; but there appear to be many gradational forms between the two species.

Monograptus becki is a prominent form of the Devil's Bridge Group, and appears just to survive into the succeeding group. It is probably allied to *M. lobiferus*, which occurs in the Castell Group.

Monograptus exiguus makes its appearance towards the top of the Devil's Bridge Group, and survives at least into the top of the Myherin Group, where it occurs in considerable numbers. About the middle of that Group it is represented by a distinct variety, which is larger than the typical species, has a more open form, and more distant thecæ.[1]

Among other species which have a restricted range may be mentioned *Monograptus resurgens*, which occurs with *Rastrites linnæi* near the junction of the Devil's Bridge and Myherin Groups;

[1] See also E. M. R. Wood (Shakespear), 'The Tarannon Series of Tarannon Quart. Journ. Geol. Soc. vol. lxii (1906) p. 679, footnote.

Monograptus galaensis, which has only been found in the latter; and *M. proteus*, which occurs rarely in the upper part of the Blaen Myherin Mudstones.

M. runcinatus, *M. crassus*, and the form referred to *M. involutus* appear to be restricted to the Devil's Bridge Group, but are represented by allied forms in the upper part of the Castell Group.

It is clear, therefore, that the gradual lithological changes between the base and the summit of the Ystwyth Stage are accompanied by gradual though quite distinct changes in the graptolitic fauna—a fact which inspires some confidence in the correctness of the stratigraphical sequence established in this great mass of folded strata.

Further, it seems certain that, given time and patience, it would be found possible to map out the subdivisions of the Ystwyth Stage in considerably more detail than I have done, and thus elucidate more fully than I have been able to do the structures within the area which they occupy.

V. The Western Limb of the Rheidol Anticlinorium.

I have only made hurried traverses of the ground that lies between Pont Erwyd or Devil's Bridge and Aberystwyth; but I believe that, at any rate from Devil's Bridge westwards, the rocks everywhere belong to the Ystwyth Stage. In recent years a narrow-gauge railway has been constructed from Aberystwyth to the latter place, necessitating a large number of rock-cuttings along the south side of the Rheidol Valley. For more than a mile to the west of Devil's Bridge the strata exposed along the railway and along the Aberystwyth road can be assigned to the Devil's Bridge Group; and the abundant graptolite of that group, *Monograptus nudus* var. *variabilis*, was collected in a cutting near Rhiw Fron Station, where it was associated with *M. nudus* and *M. resurgens (?)*.

To the west of this group there is a great development of massive blue-grey and dark-blue mudstones, with frequent shaly bands weathering in bright colours. On account of the excessive folding of the strata, I did not attempt to determine their exact relationships; but, from the knowledge of the sequence gained to the east of Pont Erwyd and Devil's Bridge, and the general structure of the country, I infer that the succession ascends gradually towards the west. About Capel Bangor, near the Rheidol Valley, some 6 miles west of Pont Erwyd, are several exposures of highly-cleaved blue shales; and in the railway-cutting on the south are dark-blue mudstones and shales with a massive grey speckly grit—an association of sediments which recalls the lower part of the Rhuddnant Group.

West of this, on both sides of the Rheidol Valley, the grits referred to the Aberystwyth Grit Group commence. Near their eastern limit they form beds of 2 to 4 inches in thickness, which alternate with dark-blue shales. Such a type is seen near Loves-

grove and Capel Dewi on the north side of the valley, and about Capel Sion on the south side. The Lovesgrove beds dip eastwards, and are underlain by dark-blue shales and mudstones, which probably floor the drift-covered strike-valley followed by the Cambrian Railway. Similar grits and shales appear again on the hills to the west of that railway, and in them is the Cefn Hendre Quarry, from which Walter Keeping recorded many graptolites. This quarry was exhaustively searched on more than one occasion, and a large number of specimens of *Monograptus* cf. *exiguus* was obtained, associated with *M. nodifer (?)*, a single specimen of *M. turriculatus*, and other poorly-preserved species which I was unable to identify.

The abundance of the first-named form suggests a comparison with the Myherin Mudstones, where that form commonly occurs. It was not recorded by Keeping, which is rather strange, considering that at present it is difficult to find any other graptolite in the quarry.

Between Cefn Hendre and the coast the Aberystwyth Group comes on, with its typical characters; bands of dark-grey evenly-bedded grit, from 6 to 12 inches thick, alternate with thin bands of soft dark-blue mudstones, usually cleaved. This type undoubtedly denotes a higher horizon than the Cefn Hendre Quarry.

At the foot of the Alltwen Cliffs, west of Tanybwlch, I was so fortunate as to discover several graptolites in some of the mudstones; the commonest form was *Monograptus priodon*, and with it were *M. nudus*, *M. turriculatus*, and *M.* cf. *salteri*. The first-named can be obtained also in the large quarry near the Harbour. A single specimen of *Petalograptus palmeus* var. *tenuis* was collected by Mr. D. C. Evans (St. Clears), from the grit-quarries near Trinity Church; and a graptolite which may be referred to *Monograptus nodifer* was found by myself in the Cwm Woods Quarry, north of Aberystwyth. From the abundance of *M. priodon* in these strata, and the presence of *M. turriculatus*, this fauna compares with that of the highest Blaen Myherin Mudstones and the Rhuddnant Group; or it may perhaps denote a still higher horizon.

The Cefn Hendre beds are lithologically very similar to the Grit Group which commences at Llyn Rhuddnant; there appears consequently to be some discrepancy between the lithological and the palæontological evidence, suggesting that the conditions of the Aberystwyth Grit Group commenced somewhat earlier on the west of the anticlinorium than on the east. The Aberystwyth Grits, in their typical development, are not represented on the east of the anticlinorium north of the Ystwyth Valley; but they can be matched exactly far to the south of that valley, where the structure would lead one to expect higher strata than those which occur on the north. It is clear, however, on lithological and palæontological grounds, that the Aberystwyth Grits occupy a high horizon in the Ystwyth Stage, and are, in fact, the highest beds that occur in the district: this involves a considerable change from the position assigned to them by Keeping, who regarded them as the lowest beds, far lower than the Grits of Plynlimon.

VI. The Geological Structure of the District.

It will be seen from the map (Pl. XXIV) that the various rock-groups are disposed roughly in the form of an open V, the apex of which is directed southwards; and that the oldest rocks occur at the northern end of the district, while successively younger strata wrap around them on the east, south, and west. This disposition is shown most clearly in the rocks of the Plynlimon and Pont Erwyd Stages; the area of the Ystwyth Stage surveyed is not sufficient to show it clearly.

This disposition is a consequence of the folding of the rocks in a large 'anticlinal' fold, the nose of which dips or pitches southwards. Superposed on this primary fold is a large number of secondary anticlines and synclines, having a similar southerly pitch; these folds are usually simple, but occasionally they are complicated by smaller (tertiary) folds. Such a structure is termed an a n t i c l i n o r i u m; its greatest elevation follows the eastern slope of the Rheidol Valley from near Nant-y-Môch to Pont Erwyd, and is probably coincident with the anticlinal axis which traverses the Rheidol gorge west of Bryn-chwîth. This line of greatest elevation may be spoken of as t h e a x i s o f t h e a n t i c l i n o r i u m, though, strictly speaking, in such a structure there are several axes. It brings up the oldest beds at Nant-y-Môch, and it will be noticed that the rocks of any given group project farthest in a southerly direction along this line.[1] Its range from Nant-y-Môch to Parson's Bridge is S. 12° W. The axes of the secondary folds have an almost constant direction of S. 5°–10° W., occasionally varying from these limits by a few degrees. The pitch lies between 10° and 15° from Pont Erwyd to Plynlimon, but appears to be somewhat less to the south of Pont Erwyd. I believe also that it shows signs of diminishing to the north of Plynlimon, and so the area herein described may be only the southern half of an elongated dome-shaped elevation. The axial planes of the folds are, as a rule, vertical, that is, the folds are of the symmetrical type, the dip in the limbs varying in different localities from 30° to 60°. Occasionally a steeper dip than that just mentioned, even up to verticality, may be observed; but no general rule can be given as to its direction. On account of the sharpness of the folds the outcrops of their two limbs do not, in general, include an angle greater than 30°, and it is frequently less. The average strike is, therefore, nearly north and south; strictly speaking, it has the same average direction as the folding axes, since the folds are so nearly symmetrical.

On account of the strong pitch the average strike is, however, of little importance, except as a rough indication of the direction of the folding axes. It would be, for instance, quite wrong to expect rocks which crop out at a given place to appear again half a mile

[1] The Plynlimon Grits west of Drybedd seem to offer an exception to this statement, but it is probable that they extend farther south than is indicated on the map. The solid geology thereabouts is largely concealed by glacial deposits.

away along the strike (average strike being understood). The rocks at such places would be invariably higher or lower in the sequence, but the same beds may appear over and over again across the strike.

I lay some stress on this, because it was a lack of recognition of the strong pitch and its results that led the earlier investigators of the district astray: namely, Sedgwick, Ramsay, and Walter Keeping, who all regarded the Plynlimon Grits and those in the neighbourhood of Cwm Ystwyth, for instance, as one and the same, because they occurred on the same strike. In reality, however, they are separated by a thickness of strata amounting to nearly a mile.

It will be observed on the map (Pl. XXIV) that the place-names after which the main divisions are called lie more or less on north-and-south lines, as, for instance, Nant-y-Môch, Bryn-glâs, Pont Erwyd, and Devil's Bridge; therefore the direct sequence is obtained by going along the strike, and not across as in unfolded districts.

It will be noticed that any given boundary has a definite trend, and the noses of the anticlines or synclines lie nearly on a straight line (due allowance being made for the influence of the form of the ground) which makes a large angle with the actual course of the boundary. Further, the 'trend-lines' of different boundaries on one limb of the anticlinorium are nearly parallel, and those of any given boundary on opposite limbs of the anticlinorium meet at a large angle near its apex. These 'trend-lines' may be regarded as the generalized strike of the beds in the limbs of the anticlinorium, and lines drawn at right angles to them may be regarded as defining the direction of the generalized dip. If the thickness of strata between any two 'trend-lines' be known from direct observation, this dip can be calculated. Using for this purpose, on the eastern limb the thickness of the Bryn-glâs Mudstones, and on the western limb the combined thicknesses of the Eisteddfa and the Rheidol Groups, the generalized dips work out at about 20° in each limb, that is, the anticlinorium is symmetrical. From the directions of the 'trend-lines' in each limb, and the value of this dip, the direction of the axis and the average pitch of the anticlinorium can be calculated. The former works out to S. 10° W., which agrees nearly with the direction S. 12° W. of the axis of greatest elevation between Nant-y-Môch and Pont Erwyd. The average pitch as calculated is 11°, which agrees with observation very closely. It is interesting to compare the thickness of the Plynlimon Stage as calculated (from the value of the pitch thus determined and the width of the outcrop in the direction of the main axis), with the value obtained by direct estimation. The calculated thickness is 3200 feet (allowance being made for the form of the ground); while the thickness estimated in the Drosgol section and elsewhere lies between 2900 feet and 3400 feet, according as the minimum or maximum thickness of the Nant-y-Môch Flags is taken. The agreement is thus remarkably close. These results show also that the average pitch of the anticlinorium agrees

closely with the observed and calculated pitch of the individual folds of which it is built up.

The relation of the 'trend-lines' to the actual outcrop and to the average strike of the beds has an important bearing on imperfectly exposed folded districts, where 'trend-lines' only (or an approximation to them) can be mapped, and where therefore the boundary-lines frequently cross the apparent strike at a large angle. In such cases it may be inferred that the structure is one of pitching folds, and that the actual boundaries are probably zigzag lines.

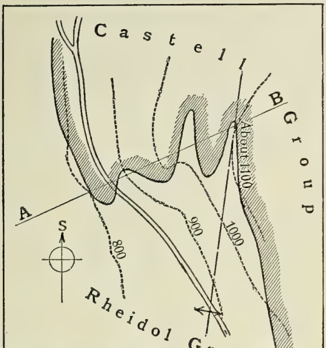
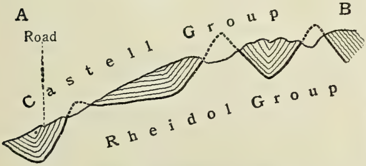


Fig. 14.—Plan of folding, about half a mile north of Pont Erwyd. Scale: 6 inches = 1 mile.

Fig. 15.—*Section along the line* AB *in fig. 14, looking southwards. (Section No. VIII on the Map, Pl. XXIV.)*



[Scale: 12 inches = 1 mile.]

In certain parts of the present district the 'trend-lines' range for short distances at right angles to the average strike; the best examples are seen in the outcrop of the grit-bed in the Rhuddnant Group south of Llyn Rhuddnant, and in the base of the Castell Group near Pont Erwyd; the latter case deserves brief mention.

The base of the Castell Group, for about half a mile to the north of Pont Erwyd, runs below the road on the west side of the valley at about the 800-foot contour (see plan & section, figs. 14 & 15). It then meets with a succession of sharp folds, and trends at right angles to its previous course for about a furlong; when it resumes its north-and-south direction, it is far above the level of the road (nearly at 1100 feet). The effect of the folded belt has been, therefore, not only to shift the outcrop laterally, but to produce a marked change in its level on both sides of the belt. In fact, it simulates closely the effect of a normal fault across the strike; but, as the course of the strata can be

clearly seen on the ground, the nature of the structure is obvious (see fig. 15, p. 523). In the absence of clear exposures, however, a normal fault would seem the most natural explanation. What is probably the same folded belt is visible in the lower strata of the Pont Erwyd Stage, in the Rheidol near Craignant-mawr.

The remarkable variation in the width of an outcrop in different parts is another consequence of the folding of the rocks. Thus, at Eisteddfa Gurig, the Eisteddfa and Rheidol Groups are contained in a width of 350 yards; while about a mile to the south the same strata occupy more than five times that width, although this is partly accounted for by the form of the ground. A comparison of fig. 3 with fig. 4 (p. 476) will make it clear how this difference arises.

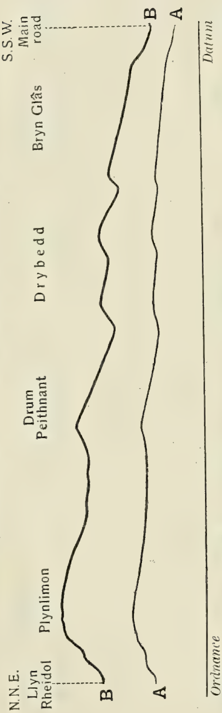


Fig. 16.—*Section illustrating the outline of the ground produced by pitching folds.* (*Section No. VII on the Map, Pl. XXIV.*)

[Scales, horizontal: 1 inch = 1 mile; vertical, in A: 1 inch = 1 mile; in B: 2 inches = 1 mile.]

With regard to the individual folds, it may be doubted whether they persist far in either direction. On comparing the two sections just mentioned it will be seen that the deep syncline in Nant Nôd has been replaced in a distance of about a mile by a very shallow synclinorium, while the complementary anticline in Afon Tarenig can scarcely be recognized.

Again, on following the anticline which brings up the Rheidol Group on the south side of the Castell Fault south of Fuches-gau, the crest may be seen to flatten gradually in a southerly direction until finally a syncline develops on that line, while a low anticline arises on the east and another on the west. If fig. 12 (p. 508) be examined, a shallow anticlinorium will be observed on Mynydd-yr-Ychion, composed of a well-marked syncline bounded on each side by a sharp anticline. This structure lies exactly in the range of the structure just mentioned, and probably represents it in a more advanced stage, but it still retains its anticlinal character.

This replacement of a single fold by compound folds probably takes place frequently; but the general characters of sections taken across the strike as illustrated by fig. 12 (p. 508) remain unchanged. An excellent idea of these structures is given also by the horizontal sections of the Geological Survey published about 1845.

Disregarding these replacements, which probably occur as frequently in one direction as in the other, a prominent fold can generally be recognized in several boundaries. For instance, the Craig-Yspio anticline ranges for the sharp anticline which brings up the Rheidol Group on the south side of the fault in Nant Meirch; and the anticline immediately to the west of it can be recognized clearly in the Drosgol Grits, the Eisteddfa Group, the Castell Group, and in the Devil's Bridge Group, and possibly within that group on Mynydd-yr-Ychion, as mentioned above. Numerous other instances might be cited.

The influence of the pitch upon the topography is one of the salient features of the district. If the hills in the Plynlimon area and to the north of Pont Erwyd be viewed across the strike, one is immediately reminded of dip-slopes and escarpments. On closer examination this suggestion is borne out, though the slopes are not dip-slopes in the ordinary sense of the expression, but may be termed 'pitch-slopes,' the outline of the hills conforming closely to the pitch of the folds. This is illustrated by the outline-section (fig. 16, p. 524) from Plynlimon to Pont Erwyd: the southern slopes, such as Plynlimon, Drum Peithnant, Drybedd, and Bryn-glâs, are all characteristically long and gentle, while the northern slopes are short and abrupt.

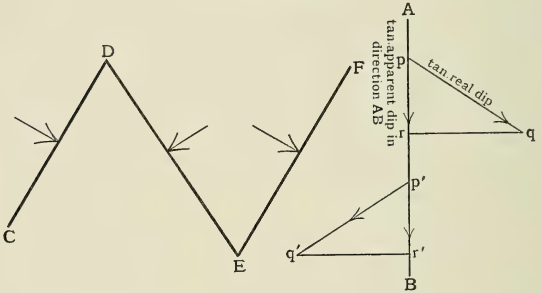
Of individual hills, however, the best examples are the prominent hills of Dinas and Disgwylfa-fawr, in which the hard Castell Beds project northwards as synclinal spurs far into the relatively low ground occupied by the underlying softer rocks. Their form is an accurate index to the pitch of the folds, and indeed its value may often be determined by observing the slope of the hills.

To the south of Pont Erwyd, and especially around Devil's Bridge, the hills are almost flat-topped, or at most have a gentle southerly inclination, which is in agreement with other evidence of a diminishing pitch in that direction.

The influence of the pitch upon the appearance of many of the hillsides also calls for some comment. For various combined reasons, among which the direction of the axes of folding (or the average strike) and the prevailing direction of cleavage are probably the most important, many of the more prominent hills range a little west of south and east of north; and, when these hills are viewed across the strike, the outcrops of alternating hard and soft beds give them a terraced appearance, and whatever the direction of the dip all the terraces have a gentle southerly inclination. The diagram (fig. 17, p. 526) illustrates how this southerly inclination is a result of the pitching of the folds. AB represents the direction of the hill-slopes which

is nearly north and south, CDEF is the outcrop of any given bed, and the arrows represent the direction of the dip. When the pitch is to the south (that is, from A to B) the limbs of the anticlines converge in that direction, and the limbs of the synclines in the opposite direction; and it will be seen from the triangles pqr, $p'q'r'$ constructed on AB, that in each limb there is a component of the dip in the direction of the pitch, that is, pr for the dip pq, and $p'r'$ for the dip $p'q'$. Therefore the outcrop of the beds in either limb, on any slope parallel to AB, will have an apparent dip in that direction. If there were no pitch the terraces would be horizontal, while if the pitch were to the north they would incline from B towards A.

Fig. 17.—*Diagram illustrating the effect of pitch on the apparent dip of rock-outcrops.*



Further, so long as AB lies anywhere between CD and DE or between DE and EF, there will always be a component of every dip in the direction AB: if the hillsides in the Pont Erwyd district, for instance, range in a direction anywhere between south and south-south-west, the outcrops of the beds on those slopes will always have an apparent dip in a southerly direction. This effect is very evident on the east side of Drosgol, on the slopes of Dinas and Disgwylfa-fawr, south of Dyffryn Castell, on the sides of the hills bordering the Rheidol Valley between Pont Erwyd and Devil's Bridge, and in numerous other instances. The value of the apparent dip is in general different from, and bears no simple relation to, the pitch. It affords a ready means of detecting whether the folds pitch or not, but the actual value of the pitch cannot be deduced from it.

Faults.

Strike-faults.—Few strike-faults of any importance have been detected, but it is quite possible that their number is greater than I suspected. Several may be seen in the Rheidol gorge near Bryn-chwîth, where they are generally overthrusts from the west, but the throw only amounts to a few feet (see Pl. XXV). The most powerful is the one near the main anticline in the gorge; it brings the *acuminatus* beds against the upper part of the *atavus* beds. The throw at that point must be about 50 yards to the east; but, as the fault-plane is nearly vertical, it is impossible to say whether it is a normal fault or an overthrust. So far as I have observed, none of the strike-faults carry ore.

Transverse faults.—These are normal faults, usually with a nearly vertical plane of fracture, and they generally carry one or more of the ores of lead, zinc, copper, and sometimes manganese (as on Drosgol). Most of them have a nearly constant direction of east-north-east and west-south-west, and cut cleanly across the folds, behaving as if they were of posterior date. The throw varies considerably, not only from one fault to another, but also in the same fault in different parts of its course, as might be expected from the folding of the rocks which it traverses. Several veins are marked on the Geological Survey Map (Old Series) which I could not detect as faults by mapping; but two of them, the Castell Fault and the Camddwr Fault, can be traced with ease, and have a considerable downthrow: in the former varying from about 30 to about 100 yards south-eastwards, and in the latter probably reaching 300 yards or more towards the north-west. Their course is usually marked on the ground by a conspicuous notch, or by an abrupt fall towards the downthrow side.

VII. Comparison with the Deposits of other British Areas.

In Table I, facing p. 530, the equivalents in other parts of Britain of the Pont Erwyd deposits are shown. A much closer comparison might, however, be instituted in many cases, as may be gathered from Table II; but it is considered unnecessary to do more than call attention to certain points of interest, especially the resemblances to and the differences from the deposits of other parts of Central Wales as described by Dr. Herbert Lapworth in the neighbourhood of Rhayader, and by Mrs. E. M. R. Shakespear in the Tarannon district.

The Bryn-glâs Mudstones are undoubtedly the equivalents of the cleaved blue-black shales which underlie the Cerig Gwynion Grits of Rhayader. They agree not only in their lithological characters, but also in their peculiar 'double cleavage' which gives them the appearance of much greater antiquity than those grits. I have, however, given reasons for supposing that this feature is due to

their physical characters, and does not necessarily indicate that two sets of movements were required to produce it.

In the Rhayader district the existence of lower beds of the Plynlimon Stage is perhaps indicated by the dark shales

'often intermixed with grits and sandstones, and occasionally with beds of conglomerate'[1]

which extend for several miles south and east of Rhayader.

The conspicuous Cerig Gwynion Grits, which form the base of the Gwastaden Group near Rhayader, are unrepresented in the Pont Erwyd district, where the greatest difficulty was experienced in finding a satisfactory base-line. There is reason to believe that they are of local occurrence even in the neighbourhood of Rhayader, for at the extreme eastern limit of that district

'where the grits have dwindled down to extreme tenuity, there seems evidence of a passage upward from these Blue-black Shales to the Gwastaden Group: for . . . . it is almost an impossibility, in the field, to say where the one group ends and the other begins' (*op. cit.* p. 96).

That the absence of the grits in the Pont Erwyd district is not due to overlap within the Pont Erwyd Stage is sufficiently proved by the fact that the lowest zone in that district indicates, if anything, a lower horizon than any fossiliferous beds near Rhayader.

I was unable to separate the zones of *Cephalograptus (?) acuminatus* and *Mesograptus modestus*, as has been done in other districts; the latter occurs throughout the Eisteddfa Group, and is accompanied everywhere in the upper part by *C. (?) acuminatus*. It is possible that the *modestus* zone may be represented in part by the lower portion of my zone of *Monograptus atavus*, since the characteristic form was only obtained near the top of the zone. Or again, it may be equivalent to the upper portion of my *acuminatus* zone, that fossil having perhaps a greater range than in the Rhayader district.

There is also a slight difference in meaning attached to the zone of *Monograptus cyphus* in the two districts. At Rhayader it is probably equivalent to the zones of *M. rheidolensis* and *M. cyphus* in the Pont Erwyd area.

The characteristic *leptotheca* band was by Dr. H. Lapworth ascribed to the *M. convolutus* zone, whereas in the area here described I have given my reasons for including it with the *M. communis* zone. However, the band is so clearly a link between the two zones, that it is of little importance which view is adopted.

The remarkable fact has been established that the great Caban-Conglomerate Group of Rhayader is entirely absent in the Pont-Erwyd region, although the localities in the two districts where the contemporaneous deposits occur are only about 15 miles apart. Further, there is a complete and gradual passage, both lithological and palæontological, throughout the Castell Group, the upper part of which is palæontologically equivalent to the Caban Group. The marked unconformity at the base of that group has, therefore, completely disappeared in that distance. The graptolites obtained

[1] See Quart. Journ. Geol. Soc. vol. lvi (1900) p. 96.

from the *M. sedgwicki* grits (or Gafallt Beds) of Rhayader agree closely with those of the *M. sedgwicki* zone in the Fuches-wen section and elsewhere, the rarity or absence of *M. tenuis* pointing perhaps to an horizon somewhat above the base of the zone. Probably, therefore, the underlying Conglomerate Group corresponds to the lower part of the *M. sedgwicki* zone or may, perhaps, have commenced at a slightly lower horizon. It is interesting to observe that, while the Caban Group has an average thickness of about 1100 feet, the equivalent deposits in North Cardiganshire have a thickness of about 110 feet, or only one-tenth as great.

In the Rhayader district, while no subdivision of the Rhayader Pale Slates was attempted, the graptolites obtained from them agree closely with those of the Ystwyth Stage.

The Pont Erwyd sequence presents a striking similarity to that of the recently described Tarannon district. The most important exception is the absence of the *M. cyphus* zone in that district, as observed by Mrs. Shakespear. It is quite possible that, in the disturbed tracts along which the lower beds occur, that zone may have been faulted out. The zones of *Dimorphograptus swanstoni* and *Monograptus fimbriatus* are undoubtedly equivalent to the zones of *M. atavus* and *M. communis* respectively in the Pont Erwyd district; but, as at Rhayader, the *leptotheca* band has been included with the zone of *M. convolutus*. The higher zones of the Dolgadfan and Twymyn Groups are the equivalents of the Castell Group, agreeing therewith in fauna, lithology, and thickness. The band with *M. 'discretus'* (=*tenuis*) and *M. sedgwicki* matches exactly the one near the Fuches-wen quarry.

The zone of *Rastrites maximus* was included by Mrs. Shakespear with the Brynmair Group of the Tarannon Series: its fauna shows affinities with the underlying and with the overlying beds. This is also the case in the Pont Erwyd district; but there the lithological character of the beds containing *R. maximus* unites them more closely with the *sedgwicki* zone than with the overlying Devil's Bridge Group.

The Devil's Bridge Group coincides in the main with the Brynmair Group, although the limits chosen for the two may not be identical. The Cardiganshire beds seem to be more sandy than those in the Tarannon district, and perhaps somewhat thicker; but the presence of *Monograptus turriculatus*, *M. becki*, *M. runcinatus*, and *Rastrites linnæi*, and the absence or rarity of forms such as *Monograptus marri*, *M. exiguus*, and *M. galaensis* in both areas, are strong points of resemblance.

The Myherin Group, again, may be matched in the Gelli Group of Tarannon, both being characterized by the prevalence of the last-named graptolites. Also there is a suggestion in the latter district of a twofold lithological division, corresponding with the Dolwen Mudstones and the Blaen Myherin Mudstones. The most remarkable difference is the absence in the Pont Erwyd district of forms like *Monograptus crispus*, *M. discus*, and *M. subconicus*, which are

characteristic of the Gelli Beds, coupled with the abundance of *Monograptus turriculatus* which only occurs rarely in those beds. So closely do the lithological characters and the rest of the fauna agree, however, that one is forced to compare the two sets of deposits; though it would seem that the physical conditions under which the Gelli Beds were laid down may have commenced at a somewhat earlier stage in the Cardiganshire district.

The Rhuddnant Group in its lithological characters strongly recalls the beds about the base of the Talerddig Grits of Tarannon; but the critical graptolites of those grits have not been found, while *Monograptus turriculatus* still survives, a suggestion again that the lithological changes occur at lower horizons than in the Tarannon district.

The higher beds of the Talerddig Grits are probably represented to the south of the Ystwyth Valley, and therefore outside the limits of the district here dealt with. It is of some interest that in the hills some 6 or 7 miles south-east of Tregaron, and some 12 miles south of the Ystwyth, this great grit-group is succeeded by purple and green beds precisely similar in character to the Dolgau Mudstones which succeed the Talerddig Grits; but, as no fossils have been obtained from them, I cannot say whether they correspond palæontologically to those mudstones.

As to more distant British areas, the Pont Erwyd succession shows several points of agreement with the Stockdale Shales of the Lake District, despite the great difference in the actual thickness of the corresponding deposits in the two areas. The same fossils occur in the same order in both districts, and to a certain extent the same types of lithological change may be observed at corresponding horizons, especially in the zones of *M. fimbriatus*, *M. convolutus*, and *M. sedgwicki*. In these zones, it is possible in certain cases to identify individual bands of graptolitic shale by means of their fauna. Of these the *leptotheca* band, equivalent to the *argenteus*-band, and the *tenuis* [=*discretus*] band near the base of the *sedgwicki* zone may be quoted as examples. In the middle of the *argenteus* band a peculiar thin pale-greenish band, called the 'green streak', was observed to persist over a wide area in the Lake District. It is rather remarkable that, as noted in this paper, a thin flag of a peculiar pale greenish-grey was found to occur near the middle of the *leptotheca* band wherever that band was investigated. A further remarkable resemblance is shown by the strong jointing of the lower beds of the *Monograptus convolutus* zone.

When the graptolites of the South of Scotland are revised in the light of recent investigations, it will be possible to institute a very close comparison between them and the Welsh deposits. As this has been done as far as possible for the Rhayader and Tarannon districts, it is unnecessary to go into it again for the Cardiganshire deposits which agree so closely with the latter.

F THE NORTH CARDIGA ER PARTS OF BRITAIN.

ayader istrict.	T I	Lake District.	Haverfordwest.
hayader Pale	? Talerdd G	Lower Browgill Beds.	
Slates.	Bryn		
n Group. nformity.	Twy	pper Skelgill Beds.	
	Dolg	iddle Skelgill Beds.	
den Group.	? Ga Fach	ower Skelgill Beds.	Lower part of Lower Llandovery.
ue-black shale.		? Ashgillian.	? Redhill and Slade Beds.

TABLE I.—CORRELATION OF THE NORTH CARDIGANSHIRE ROCKS WITH THEIR EQUIVALENTS IN OTHER PARTS OF BRITAIN.

	Pont Erwyd District.	Rhayader District.	Tarannon District.	Moffat, etc.	Girvan.	Lake District.	Haverfordwest.
YSTWYTH STAGE	Rhuddnant Group	Rhayader Pale Slates	? Talerddig Grits (part of)	Upper Gala Beds ?	Penkill Group.	Browgill Beds	
	Myherin Group.		Gelli Beds				
	Devil's Bridge Group		Brynmair Beds.	Lower Gala.			
PONT ERWYD STAGE	Castell Group	Caban Group. Unconformity	Twymyn Beds	Upper Birkhill.	Camregan Group.	Upper Skelgill Bed	
			Dolgadfan Beds		Saugh Hill Group.	Middle Skelgill Beds	
	Rheidol Group	Gwastaden Group	? Gap	Lower Birkhill.		Lower Skelgill Beds	Lower part of Lower Llandovery.
			Fachdre Beds				
	Eisteddfa Group				Mulloch Hill Group.		
PLYNLIMON STAGE.	Bryn-glås Mudstones.	Cleaved blue-black shale.		Upper Hartfell.	Drummuck Group.	Ashgillian.	? Redhill and Slade Beds
	Drosgol Grits.						
	Nant-y-Môch Flags.						

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TABLE II.—OCCURRENCE AND RANGE OF THE GRAPTOLITES IN THE HARTFELL-VALENTIAN SUCCESSION.

[c. = common; v.c. = very common; r. = rare; cf. = compare with]

PONT ERWYD AND ABERYSTWYTH DISTRICTS. — PLYNLIMON STAGE (Zone of *Dicellograptus anceps*; Dwyryd Grits; Brynglas Mudstones). PONT ERWYD STAGE: Eisteddfa Group (Zone of *Cephalograptus* (?) [illegible]); Rheidol Group (Zone of *Monograptus* [illegible]; Zone of *Monograptus rheidolensis*; Zone of *Monograptus* [illegible]; Zone of *Monograptus* [illegible]; Zone of *Monograptus* [illegible]); Castell Group (Zone of *Monograptus convolutus*; Zone of *Cephalograptus cometa*; Zone of *Monograptus sedgwicki*). YSTWYTH STAGE: East of the Main Anticline (Mylor Beds: Devil's Bridge Beds; Dolwen Mudstones; Black Mylor Mudstones; Rhayader Beds; Blaen-y-Cwm [illegible]); West of the Main Anticline ([illegible]).

RHAYADER DISTRICT. — Gwastaden Group (Cerig Gwynion Grits; Micaceous Flags and Grits; Zone of *Diplograptus* [illegible]; Zone of *Monograptus* [illegible]; Dyfnant Flags; Zone of *Monograptus* [illegible]; Zone of *Monograptus* [illegible]; Gigrin Mudstones; Zone of *Monograptus* [illegible]; Pale-grey Mudstones; [illegible]); Caban Group (Gafallt Beds; [illegible]).

TARANNON DISTRICT. — LLANDOVERY SERIES (Cwmere Beds; Dolgwynion [illegible]; [illegible]); TARANNON SERIES (Tarannon [illegible]; Gwar Beds; Talerddig Grits); HARTFELL (Upper Hartfell).

SOUTH SCOTLAND, MOFFAT, &c. — BIRKHILL STAGE: Lower Birkhill (Zone of *Dicellograptus anceps*; Zone of *Orthograptus vesiculosus*; Zone of *Monograptus gregarius*); Upper Birkhill (Zone of *Cephalograptus cometa*; Zone of *Monograptus spinigerus*; Zone of *Rastrites maximus*). GALA STAGE (Lower Gala; Upper Gala).

LAKE DISTRICT. — SKELGILL STAGE: Lower Skelgill; Middle Skelgill (Zone of *Monograptus convolutus*; Zone of *Monograptus clingani*; [illegible]); Upper Skelgill (Zone of *Rastrites maximus*). BROWGILL STAGE: Lower Browgill ([illegible] *turriculatus*; [illegible] *crispus*).

Monograptus annulosus, Törnq.	[illegible]
Monograptus argenteus, Nich.	[illegible]
Monograptus argutus, Lapw.	[illegible]
Monograptus atavus, sp. nov.	[illegible]
Monograptus [illegible]	[illegible]
Monograptus becki (Barr.)	[illegible]
Monograptus [illegible] (Carr.)	[illegible]
Monograptus [illegible], Lapw.	[illegible]
Monograptus communis var.	[illegible]
Monograptus concinnus, Lapw.	[illegible]
Monograptus convolutus (His.)	[illegible]
Monograptus convolutus var.	[illegible]
Monograptus crassus, Lapw.	[illegible]
Monograptus crenularis, Lapw.	[illegible]
Monograptus crenularis, var. α, Lapw.	[illegible]
Monograptus cygneus, Törnq.	[illegible]
Monograptus cyphus, Lapw.	[illegible]
Monograptus decipiens, Törnq.	[illegible]
Monograptus densus, Perner	[illegible]
Monograptus cf. *dextrorsus*, Linnars.	[illegible]
Monograptus cf. *difformis*, Törnq.	[illegible]
Monograptus distans (Portl.)	[illegible]
Monograptus exiguus (Nich.)	[illegible]
Monograptus fimbriatus (Nich.)	[illegible]
Monograptus cf. [illegible]	[illegible]
Monograptus [illegible], Lapw.	[illegible]
Monograptus [illegible] (Barr.)	[illegible]
Monograptus [illegible]	[illegible]
Monograptus [illegible]	[illegible]
Monograptus [illegible], Perner	[illegible]
Monograptus [illegible]	[illegible]
Monograptus [illegible]	[illegible]
Monograptus [illegible]	[illegible]
Monograptus [illegible]	[illegible]
Monograptus jaculum, Lapw.	[illegible]
Monograptus leptotheca, Lapw.	[illegible]
Monograptus limatulus, Törnq.	[illegible]
Monograptus lobiferus (M'Coy) (sensu stricto)	[illegible]
Monograptus marri, Perner	[illegible]
Monograptus cf. *millepeda* (M'Coy)	[illegible]
Monograptus cf. *miren*s, Perner [= Barr. MS.]	[illegible]
Monograptus nodifer, Törnq.	[illegible]
Monograptus nudus, Lapw.	[illegible]
Monograptus nudus, var. *variabilis*, Perner	[illegible]
Monograptus priodon (Bronn)	[illegible]
Monograptus proteus (Barr.)	[illegible]
Monograptus regularis, Tö[illegible]	[illegible]
Monograptus resurgens, L[illegible]	[illegible]
Monograptus revolutus, Kurck	[illegible]
Monograptus revolutus, var. *austerus*, Törnq.	[illegible]
Monograptus rheidolensis, sp. nov.	[illegible]
Monograptus runcinatus, Lapw.	[illegible]
Monograptus [illegible], Lapw.	[illegible]
Monograptus [illegible], Lapw.	[illegible]
Monograptus [illegible]	[illegible]
Monograptus [illegible]	[illegible]
Monograptus [illegible]	[illegible]
Monograptus [illegible], Lapw.	[illegible]
Monograptus [illegible]	[illegible]
Monograptus [illegible]	[illegible]
Monograptus [illegible]	[illegible]
Monograptus turriculatus (Barr.)	[illegible]
Monograptus cf. [illegible]	[illegible]
Rastrites approximatus, Perner	[illegible]
Rastrites [illegible], Carr.	[illegible]
Rastrites hybridus, Lapw.	[illegible]
Rastrites [illegible], Barr.	[illegible]
Rastrites longispinus, Perner	[illegible]
Rastrites maximus, Carr.	[illegible]
Rastrites [illegible], Barr.	[illegible]
Rastrites [illegible], Törnq.	[illegible]
Dimorphograptus confertus (Nich.) var. *swanstoni*, Lapw.	[illegible]
Dimorphograptus erectus, E. & W.	[illegible]
Dimorphograptus extenuatus, E. & W.	[illegible]
Diplograptus (Orthograptus) [illegible]	[illegible]
Diplograptus (Orthograptus) [illegible]	[illegible]
Diplograptus (Orthograptus) [illegible] (Nich.)	[illegible]
Diplograptus (Orthograptus) [illegible], E. & W.	[illegible]
Diplograptus (Orthograptus) truncatus (Lapw.)	[illegible]
Diplograptus (Orthograptus) cf. *truncatus* (Lapw.)	[illegible]
Diplograptus (Orthograptus) vesiculosus (Nich.)	[illegible]
Diplograptus (Orthograptus) vesiculosus, var. [illegible]	[illegible]
Diplograptus (Mesograptus) magnus (H. Lapw.)	[illegible]
Diplograptus (Mesograptus) modestus (Lapw.)	[illegible]
Diplograptus (Mesograptus) modestus, var. *diminutus*, E. & W.	[illegible]
Diplograptus (Mesograptus) modestus, var. *parvulus* (H. Lapw.)	[illegible]
Diplograptus (Glyptograptus) persculptus (Carr.)	[illegible]
Diplograptus (Glyptograptus) [illegible], E. & W.	[illegible]
Diplograptus (Glyptograptus) serratus, var. [illegible], E. & W.	[illegible]
Diplograptus (Glyptograptus) [illegible] (Nich.)	[illegible]
Diplograptus (Glyptograptus) [illegible] (Nich.)	[illegible]
Diplograptus (Glyptograptus) tamariscus, var. *incertus*, E. & W.	[illegible]
Diplograptus (Petalograptus) [illegible], E. & W.	[illegible]
Diplograptus (Petalograptus) [illegible], Elles	[illegible]
Diplograptus (Petalograptus) palmeus (Barr.)	[illegible]
Diplograptus (Petalograptus) palmeus, var. *latus* (Barr.)	[illegible]
Diplograptus (Petalograptus) palmeus, var. *tenuis*, Barr.	[illegible]
Diplograptus (Cephalograptus) [illegible] (Nich.)	[illegible]
Diplograptus (Cephalograptus) [illegible] (Bronn)	[illegible]
Climacograptus hughesi (Nich.)	[illegible]
Climacograptus [illegible], Törnq.	[illegible]
Climacograptus rectangularis (M'Coy)	[illegible]
Climacograptus scalaris (His.)	[illegible]
Climacograptus scalaris, var. *miserabilis*, E. & W.	[illegible]
Climacograptus scalaris, var. [illegible], Lapw.	[illegible]
Climacograptus [illegible], E. & W.	[illegible]
Retiolites (Gothograptus) [illegible] (Nich.)	[illegible]
Dicellograptus anceps (Nich.)	[illegible]
Acanthograptus [illegible], Lapw.	[illegible]
Dictyonema sp.	[illegible]

The Scottish deposits afford the nearest faunal analogy with the Plynlimon Stage, despite the great difference in the thickness of the deposits and in their lithological characters.

The Nant-y-Môch Flags with *Dicellograptus anceps* and abundant forms of the *Orthograptus-truncatus* group clearly correspond to the fossiliferous lower part of the *D. anceps* zone of the Upper Hartfell. In that region the base of the overlying Birkhill Shales consists of a calcareous band crowded with *Climacograptus scalaris* var. *normalis*, which underlies or forms the base of the zone of *Cephalograptus (?) acuminatus*. This calcareous band seems to correspond with the upper part of the zone of *Glyptograptus persculptus* as developed near Fuches-gau, where the above-mentioned variety of *Climacograptus* is especially abundant. The base of the Pont Erwyd Stage is, therefore, at an horizon at least as low as the base of the Birkhill Shales. The two upper groups of the Plynlimon Stage—the Drosgol Grits and the Bryn-glâs Mudstones—must therefore correspond to the barren green shales and mudstones which intervene in the Moffat country between the fossiliferous shales with *Dicellograptus anceps* and the base of the Birkhill Shales. As the Cardiganshire deposits are at least 2500 feet thick, while the corresponding Scottish deposits are only about 12 feet thick, it will be seen how great is the attenuation in passing from one district to the other.

In conclusion, I wish to express my thanks to many friends for help received during the progress of the work, and especially to Dr. Herbert Lapworth for much encouragement during the early stages, and to Mrs. E. M. R. Shakespear and Miss G. L. Elles for constant advice and assistance in identifying many of the graptolites and in the difficult questions of nomenclature. I should also like to tender my thanks to Prof. J. R. Ainsworth Davis, late of the University College of Wales, Aberystwyth, for hospitality extended to me in the early stages, without which the work would have been hardly possible at that time.

VIII. Description of Two New Species of Graptolites.

Monograptus atavus, sp. nov. (Fig. 18 *a*, *b*, *c*, & *d*.)

1876. *Monograptus tenuis* (pars), C. Lapworth 'On Scottish Monograptidæ' Geol. Mag. dec. ii, vol. iii, p. 319 & pl. xi, probably figs. 3 *a*, 3 *d*, & 3 *i*.

Polypary of unknown but great length, narrow, gently curved or sometimes nearly straight in the distal portion. Near the proximal end the thecæ invariably lie on the convex side, but distally they sometimes occur on the concave side. The width of the polypary increases very gradually from ·01 inch (·25 mm.) at the proximal end to a maximum of about ·05 inch (1·25 mm.), a fragment of this width measuring 30 inches (76 cm.) having been

Fig. 18.—*Monograptus atavus*, sp. nov.

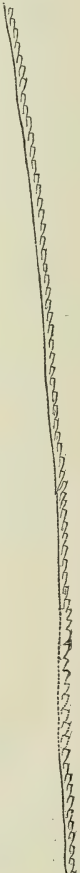
18 *b*.

Fragment near the proximal end, to show the strongly sinuous thecæ (× 5).
Rheidol Gorge (F. 13.)
Reg. no. 23710.

18 *a*.

18 *c*.

18 *d*.



18 *a*.—Fragment near the proximal end, showing the form of the thecæ and of the polypary (× 5).
Rheidol Gorge (F. 14).
Reg. no. 23706.

18 *c*. — Distal fragment, showing the form of the thecæ (× 5).
Rheidol Gorge (F. 14).
Reg. no. 23707.

18 *d*.—Distal fragment (× 2).
Rheidol Gorge (F. 13).
Reg. no. 23711.

seen ; compressed specimens are usually somewhat wider. The sicula =·05 inch (1·25 mm.) in length, its apex reaching to about the middle of the first theca. The thecæ are short tubes, five or six times as long as wide, of almost circular section, and inclined at a small angle to the direction of the virgula. In the proximal portion they are ·06 inch (1·5 mm.) long, and overlap to about a quarter of their length ; distally they increase to ·1 inch (2·5 mm.) and overlap to one-half. Their outer wall usually is strongly sinuous (see especially fig. 18 *b*) and there is sometimes a distinct excavation opposite the aperture of the theca next below. They number about twenty-three to the inch (nine in 10 mm.) along the whole length of the polypary, and in specimens in relief they are usually marked with conspicuous lines of growth. The apertural margins are simple, fairly straight, and lie perpendicular to the length of the thecæ.

Horizon and locality.—This graptolite occurs abundantly in the Pont Erwyd district, in the zones of *Monograptus atavus*, *M. cyphus*, in the lower part of the zone of *M. communis*, and less commonly in the zone of *M. rheidolensis* ; its associates are the usual graptolites of those zones.

This form has commonly been referred to *Monograptus tenuis* (Portlock) ; but, according to Miss G. L. Elles, that species is characteristic of a much higher horizon, and, as noted by Prof. Charles Lapworth, is the same as the one subsequently described as *Graptolites discretus* by Nicholson.[1]

It agrees with *M. atavus* in the general form of the polypary, but differs in all its essential characters. In compressed specimens the chief differences are that *M. tenuis* (Portl.) = *M. discretus* (Nich.) is a smaller form and has more distant thecæ, the apertural margins of which are concave, inclined and bear very acute denticles sometimes prolonged into distinct 'tags.' Specimens of the latter found in relief in the Pont Erwyd district show, however, that the two species are radically distinct.

The species most nearly allied to *M. atavus* is *M. argutus*, Lapw., with which it shows close affinities. The characters of the proximal end are almost identical, but *M. argutus* is usually more strongly curved. In the distal part the chief distinctions are the smaller size and the more highly developed thecal structure of *M. argutus* ; the sinuosity and excavation of the thecæ is more marked, their apertural margins are inclined, slightly concave, and prolonged into an acute denticle.

It is probable that the form recorded by various authors as *M. tenuis* from the Lower Birkhill rocks or their equivalents is to be referred to *M. atavus*, which appears to be confined to those rocks.

[1] H. A. Nicholson, 'On the Graptolites of the Coniston Flags, &c.' Quart. Journ. Geol. Soc. vol. xxiv (1868) p. 539 & pl. xx. figs. 12–15.

Fig. 19.—*Monograptus rheidolensis*, sp. nov.

19 *a.*

Fragment near the proximal end, showing the curvature of the polypary and the form of the thecæ (× 5).
Rheidol Gorge (F. 12).
Reg. no. 23708.

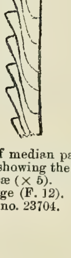
19 *b.*

Fragment showing the sicula and the first two thecæ (× 10).
Rheidol Gorge (F. 20).
Reg. no. 23705.

19 *c.*

Median fragment, showing the curvature of the polypary and the form of the thecæ (× 5).
Rheidol Gorge (F. 12).
Reg. no. 23709.

19 *d.*



Fragment of median part of polypary, showing the form of the thecæ (× 5).
Rheidol Gorge (F. 12).
Reg. no. 23704.

Monograptus rheidolensis, sp. nov. (Fig. 19 *a*, *b*, *c*, & *d*.)

Polypary of unknown length, but probably exceeding 12 inches (30 cm.), gently curved near the proximal end and almost straight distally. Width increasing slowly and uniformly from ·01 inch (·25 mm.) opposite the aperture of the first theca to ·08 inch (2 mm.) in the most distal portions. Sicula = ·2 inch (5 mm.) in length, tapering gently from a maximum width of ·005 inch (·12 mm.); its apex reaches as far as the origin of the third theca. The thecæ are long tubes, exceedingly slender about the middle of their length and expanding towards the apertures; their outer walls are concave, or bent into a gentle sigmoidal curve. They are disposed on the convex side of the polypary and are ·16 inch (4 mm.) long near the proximal end and in the distal portions, but ·2 inch (5 mm.) where the curvature of the polypary is greatest; their width at the aperture is from a tenth to a twentieth part of their length. Their overlap near the sicula is one-half, but after the first few thecæ it increases to two-thirds, each theca then originating nearly opposite to, or slightly in advance of, the aperture of the third theca below. They are inclined at a small angle to the virgula and number about thirteen to the inch (five or six in 10 mm.) near the sicula; but are more closely set distally, where there are about twenty-three to the inch (nine in 10 mm.).

The apertural margin is simple and nearly normal to the axis of the theca, or in some cases slightly everted. In compressed specimens the widening of the thecæ towards the aperture is greatly accentuated; the outer walls are then strongly concave, and the slightly everted apertural margins appear to be prolonged into a distinct lip.

Horizon and locality.—*Monograptus rheidolensis* is fairly common in the Pont Erwyd district in the zone which bears its name, and it may also occur in the succeeding zone of *M. cyphus*. Its commonest associates are *Climacograptus törnquisti*, Elles & Wood, and *Cl. hughesi*, Nich.

The thecæ of this species resemble somewhat those of *Monograptus gregarius*, Lapw., but their much greater length and overlap in *M. rheidolensis* serve to distinguish the two species even in fragments. The only species with which *M. rheidolensis* might be confounded is *M. leptotheca*, Lapw., which it resembles in the great length and overlap of the thecæ; but the greater curvature of the polypary and the details of the thecal structure sufficiently distinguish them.

The figured specimens are deposited in the Museum of Practical Geology, Jermyn Street, London, the numbers appended to the text-figures being the register-numbers of the specimens from which they were drawn.

My sincere thanks are tendered to Miss E. G. Welch, who prepared the drawings of the graptolites.

EXPLANATION OF PLATES XXIV & XXV.

Plate XXIV.

Geological map of the district around Plynlimon and Pont Erwyd, on the scale of $1\frac{1}{2}$ inches to the mile.

Note.—The distinction between the colours of the Dolwen Mudstones and the Devil's Bridge Group is not so clear as was intended.

Plate XXV.

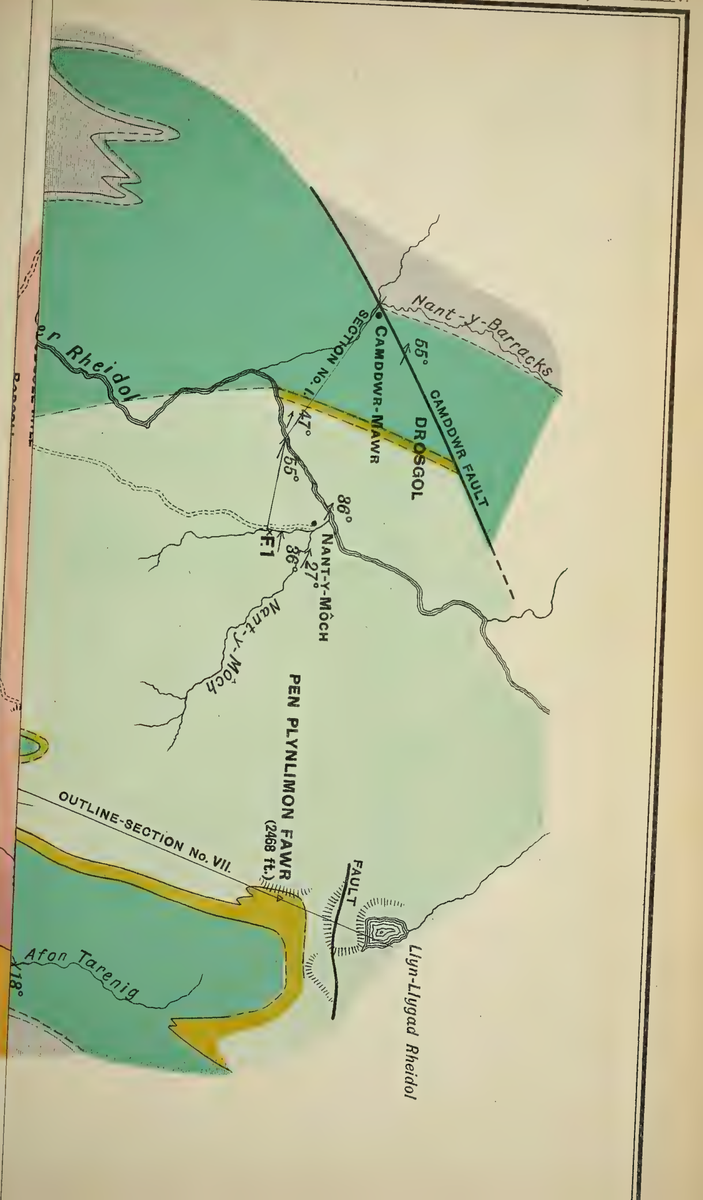
Plan of the Rheidol Gorge between Pont Erwyd and Parson's Bridge, illustrating the relationships of the zonal subdivisions and the geological structure, on the scale of 12 inches to the mile.

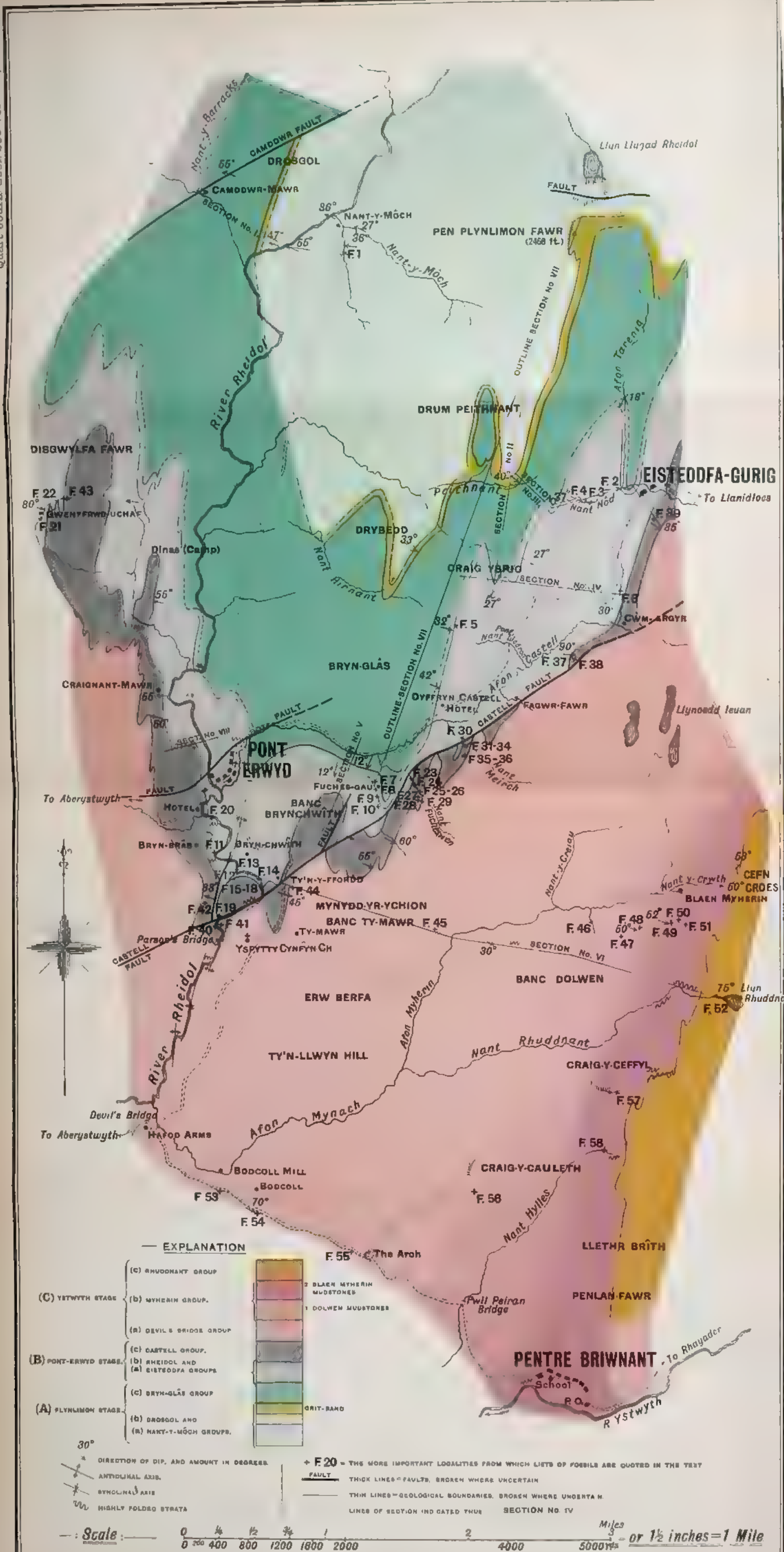
Discussion.

Dr. J. E. Marr congratulated the Author on successfully working out a district which, as he knew from a visit made with the late Walter Keeping many years ago, was one of extreme complexity. The Author had mentioned the similarity of the jointing in his *convolutus* beds to that of the same beds in the Lake District. This led the speaker to discuss the frequent importance of lithological characters for purposes of correlation,—not always the most prominent characters being of importance for this purpose, but often obscure characters the very origin of which was not yet understood. In this connexion he referred to the 'pattern' described by the Author, and asked for information concerning a certain band in the *leptotheca* zone which he understood was on the horizon of a 'green streak' in the same zone of the Lake District (known there as the *argenteus* zone). This streak had now been traced in the North of England from near Broughton-in-Furness, to Cautley near Sedbergh, a distance in a direct line of 31 miles.

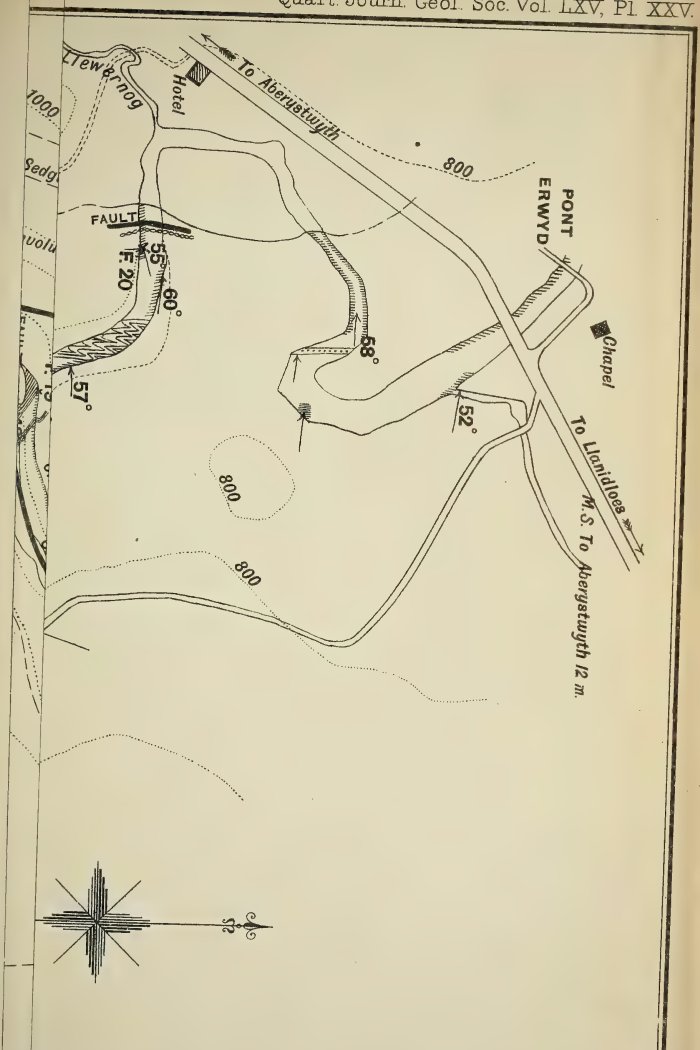
Dr. H. Lapworth congratulated the Author on the completion of a most interesting and valuable piece of work. He had visited the district with the Author, who had shown him his main sections and demonstrated the general stratigraphy. He had been greatly impressed by the remarkable lithological similarity between the rocks of this region and those of Rhayader. In the middle and upper portions of the Pont Erwyd Group it was possible almost to correlate each band with its equivalent 20 miles to the east. There were, however, one or two striking discordances, which threw light on the geological history of Mid-Wales. In the Plynlimon district the Author had found no well-marked lithological change at the base of the Lower Llandovery, such as existed at Rhayader; and here, as at Tarannon, there was a continuous passage upwards from the *convolutus* beds into the *sedgwicki* and *maximus* zones, in contrast with the pronounced unconformity at Rhayader.

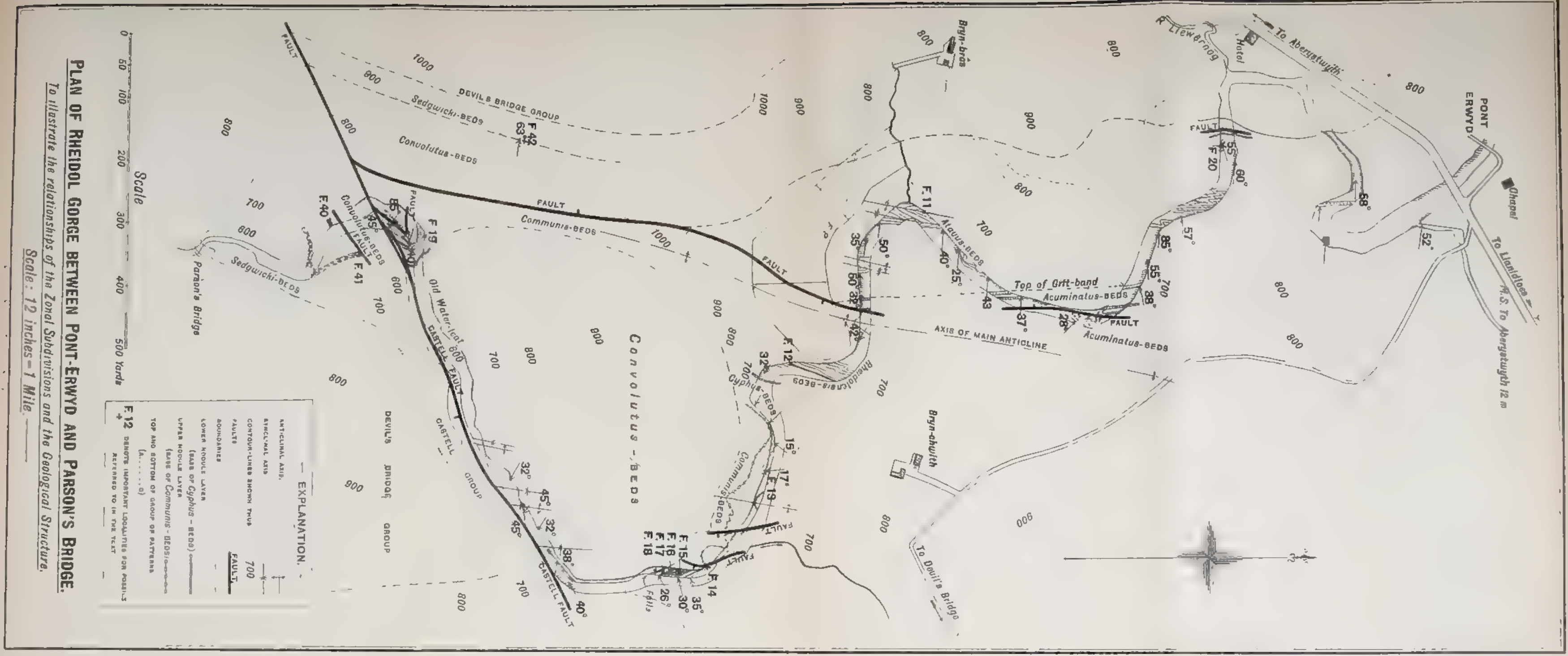
Farther north Mr. Fearnsides, at Criccieth, and the speaker, at Aberdovey, had found the Valentian rocks to be of the Lake


Nant-y-Barracks
55°
CAMDDWR FAULT
DROSGOL
CAMDDWR-MAWR
SECTION No. I.
Rheidol
47°
55°
86°
F1
36°
27°
NANT-Y-MÔCH
Nant-y-Môch
PEN PLYNLIMON FAWR
(2468 ft.)
FAULT
OUTLINE-SECTION No. VII.
Llyn-Llygad Rheidol
Afon Tarenig
18°



GEOLOGICAL MAP OF PLYNLIMON AND PONT-ERWYD DISTRICT.


To Aberystwyth
Hotel
Llewernog
1000
800
PONT ERWYD
FAULT
55°
F. 20
60°
58°
57°
Chapel
52°
800
To Llanidloes
800
M.S. To Aberystwyth 12 m.



PLAN OF RHEIDOL GORGE BETWEEN PONT-ERWYD AND PARSON'S BRIDGE.

To illustrate the relationships of the Zonal Subdivisions and the Geological Structure.

Scale: 12 inches = 1 Mile.

District type, rather than of the Rhayader type, while at Plynlimon the change had already begun. It had been left to the Author to prove conclusively the geological structure of this tantalizing region and to place its classic strata in their correct order. With the Author's careful and detailed work here, and with the far-reaching discoveries of Mrs. Shakespear at Tarannon, it might be truly said that the mystery of the vast Mid-Wales complex was solved at last. It seemed probable that the remaining area would prove to be made up of mere variations of the Plynlimon-Tarannon geology: in other words, great stretches of Tarannon rocks, with small patches of Llandovery and Hartfell brought up in anticlinal folds.

The President (Prof. Sollas) remarked on the interesting manner in which the uniform colour of the 'Welsh wilderness' had been transformed into a diversified scheme of stratigraphical structure. The constancy of lithological character on some horizons was a very suggestive fact, and under the guidance of palæontological evidence might lead to unexpected discoveries concerning the geographical features and physical conditions of past ages. The *Monograptus priodon* limestone retained its black colour and thin slabby bedding over a wide area; examples from Bohemia and Ireland were undistinguishable in hand-specimens, and were remarkably similar to others from Cincinnati in Ohio.

The Author, replying to Dr. Marr, said that one of the specimens exhibited on the table was a pale greyish-green flag about three-quarters of an inch thick, which occurred throughout the Pont Erwyd district in the centre of the *leptotheca* band. This band might be correlated with certainty with the *argenteus* zone of the Lake District, and the pale flag in the centre was almost certainly equivalent to the peculiar 'green streak' which had been found over a wide area in the Lake District, always at the centre of the *argenteus* shale-band. Dr. Herbert Lapworth had referred to the peculiar structure in the mudstones of the Plynlimon Stage as a double cleavage, and seemed to suggest that it required two series of movements to set it up. The Author was of opinion that it was the effect of a single set of movements on sediments of a certain physical constitution. In conclusion, the Author thanked the Fellows present for their cordial reception of his paper.

30. *The* Carboniferous Limestone *of* County Clare (Ireland).

By James Archibald Douglas, M.A., B.Sc., F.G.S. (Read June 16th, 1909.)

[Plates XXVI & XXVII—Fossils.]

Contents.

I. Introduction.

The work of examining the Carboniferous Limestone of County Clare was undertaken with a view to ascertaining whether the zonal sequence of the fauna, established by Dr. Arthur Vaughan for contemporaneous rocks in the Bristol district, and since proved to hold good for other localities in Great Britain, was also applicable to these beds in the West of Ireland. This district, which forms the western limit of the great limestone-plain of Central Ireland, furnishes one of the most typical examples of a limestone country in the British Isles, and it is strange that it has not attracted more attention from Irish geologists. Although Dr. Wheelton Hind [1] has studied the overlying shales and shown them to be the equivalent of the Pendleside Series, the fauna of the limestone has up to the present remained undescribed.

A brief allusion to the limestone in the extreme south of the county is given in the recent Survey Memoir on the Geology of the Limerick District; but, with the exception of accounts of cave-explorations,[2] there are, so far as I am aware, no papers bearing on the geology of Eastern Clare of more recent date than the original Memoirs published by the Irish Geological Survey in 1860 and 1863.

[1] 'Notes on the Homotaxial Equivalents of the Beds which immediately succeed the Carboniferous Limestone in the West of Ireland' Proc. Roy. Irish Acad. vol. xxv (1905) Sect. B, pp. 93–116.

[2] R. F. Scharff, R. J. Ussher, G. A. J. Cole, E. T. Newton, A. F. Dixon, & T. J. Westropp, 'The Exploration of the Caves of County Clare' Trans. Roy. Irish Acad. vol. xxxiii (1906) Sect. B, pp. 1–76.

Mapping, at that time, was executed by sole reference to the lithological characters of the rocks, and little attention seems to have been paid to their fossil contents. The evidence, now adduced by a study of the latter, necessitates very little alteration in the subdivision, the main line of division between the Lower and Upper Limestones of the Survey being found to correspond with the transition from a Tournaisian to a Viséan fauna. It will be shown, however, that the Lower Limestone Shales are not separable, as mapped at present, from the Lower Limestone, and that the Middle Limestone, or 'Calp' of other districts which is not recognized here, may still on palæontological grounds be readily distinguished from the Upper Limestone.

The meagre fauna hitherto recorded from the limestone of County Clare is, I think, due to certain adverse conditions which the nature of the country presents. In the north and centre of the county, the bare surface of the rock is exposed over vast areas; and, although the rainfall is considerable, it is nearly all absorbed directly and carried off by subterranean channels.[1] In consequence, sections afforded by river- or stream-valleys are practically absent; and, as building-material lies ready to hand on the surface of the ground, quarries exposing fresh surfaces of rock are seldom available.

The limestone is traversed by a great series of open joints or 'grikes,' the edges of which become carved and rounded by solution; and fossils, which are not often visible except in the form of hollow casts, are extremely difficult to extract. The sea-cliffs, too, afford no better collecting-ground, for the spray has etched out the limestone between high and low-water marks until it resembles a great bed of scoriaceous lava, the face of which it is impossible to penetrate.

The southern part of the county is covered to a large extent by drift and peat-bogs; the beds, however, become less horizontal and the stratigraphy is easier to make out, sections in quarries and stream-valleys, though somewhat isolated, being comparatively numerous.

From the foregoing remarks it will be readily understood that the description in minute detail of any one complete section, such as that presented by the Avon Gorge of the Bristol area, is a practical impossibility. My aim, therefore, has been to make a more or less complete examination of the whole area, and determine the more important details of the faunal succession; and it is hoped that the results included in this paper will show that a faunal correlation can undoubtedly be made with the Carboniferous Limestone of other remote localities.

[1] The amount of water carried off in this way must be considerable, and solution of the limestone very rapid. During my first visit to Ballyvaghan, it rained unceasingly for two whole days, but after its cessation all trace of moisture had disappeared in a few hours' time. During a rainy season, the sea-water of the bay is rendered brackish for some distance from shore, sufficiently so for cattle to drink it.

Fig. 1.—*Barren surface of limestone, with 'grikes': Ballyvaghan (Clare).*

E. R. L. photogr.

Fig. 2.—*Results of pluvial and marine action on the limestone: Black Head (Clare).*

E. R. L. photogr.

The large area of country dealt with, and the impracticability of working, in detail, sections many miles in length, have rendered it impossible to study carefully the evolution of any one group of organisms; but, if connecting links have been found which can be added to the rapidly lengthening chain of our knowledge of the faunal development during Avonian time, one of the objects of this paper will have been partly realized. My primary object, however, being to test the value of the generally accepted Carboniferous zone-fossils, in working the rocks of more distant regions than those already dealt with, I have not deemed it advisable to overburden the somewhat extensive list of fossils which now exists, by a description of any new or rare species which is not of practical use for zonal purposes.

II. Sequence of the Deposits.

The accompanying table (p. 542) illustrates the relation between the palæontological zones and the former stratigraphical divisions of the Geological Survey.

The vertical thicknesses, which show a considerable variation throughout the county, are taken from the Survey Memoirs; they can only be considered approximate, owing to the absence of clear measurable sections. The great thickness of the Upper Limestone, of which nearly 1500 feet must be assigned to the *Dibunophyllum*-Zone, finds a parallel in the Midland area of Derbyshire and Staffordshire.

III. Nature and Extent of the Outcrop, and Topographical Features.

The Carboniferous Limestone floors nearly the whole of Eastern Clare, from the southern shore of Galway Bay to the banks of the Shannon. This area, for the purposes of description, may be conveniently divided into a northern district comprising the baronies of Burren and Inchiquin, and a southern district comprising those of North and South Bunratty and North and South Tulla.

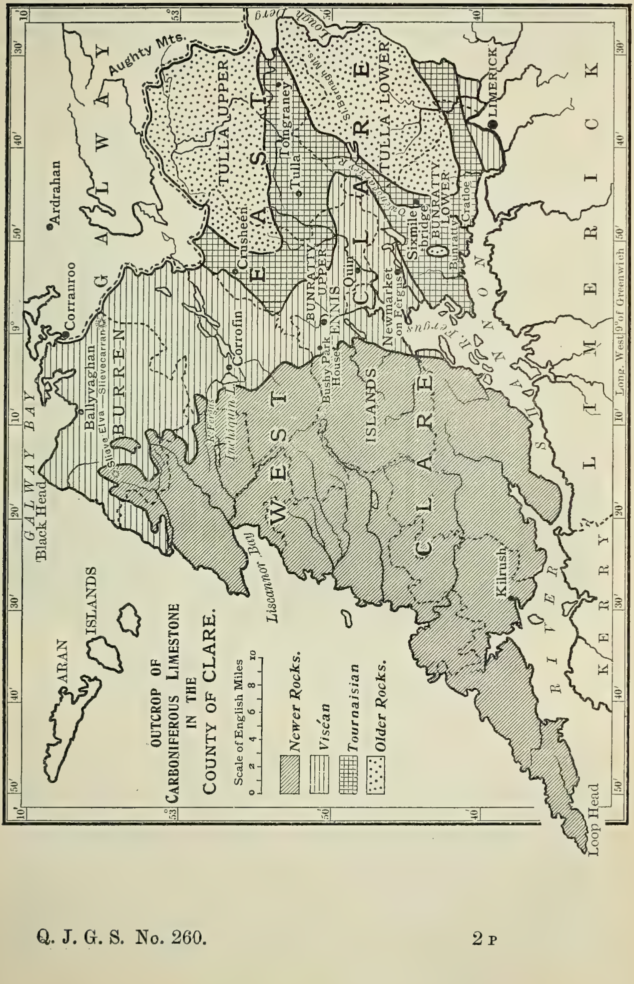
Nearly the whole of the northern district is formed by a vast elevated plateau of Upper Limestone, with a surface of bare rock many square miles in extent, practically devoid of vegetation. The beds, though slightly undulating, have an average dip of about 2° to the south and south-west, in which direction they pass beneath the Coal Measures. On the south and east, however, they end abruptly in steep escarpments with terraced sides; these great limestone-terraces can be traced for mile after mile across the country, and their formation by subaërial agencies is a point of considerable geological interest.

They are, I consider, primarily due to the influence of jointing, and the alternation of coarse and fine bedding and their unequal

Stratigraphical Zones of the Survey.	*Approximate thickness in feet.*	*Palæontological Zones and Subzones.*	*Provisional Correlation.*
BLACK GONIATITE SHALES of the Coal Measure series.	80–150	GONIATITE SHALES.[1]	
UPPER LIMESTONE. Light and dark-grey crinoidal limestones, often very argillaceous. Chert occurs in nodules and layers throughout, with a well-defined cherty zone (20–60 feet) at the base. Occasionally oolitic, and exhibiting characters indicative of deposition in shallow water. The thickness of individual beds varies from a few inches to several feet.	1900	*DIBUNOPHYLLUM*-ZONE. D_3 *Cyathaxonia* subzone. D_2 *Lonsdalia* subzone. D_1 *Dibunophyllum* θ subzone. *SEMINULA*-ZONE. S_2 *Productus cora* (mut. S_2) subzone. S_1 *Productus* aff. *semireticulatus* subzone.	VISÉAN.
LOWER UNSTRATIFIED LIMESTONE. Massive grey and mottled limestones containing abundant bryozoa. Often very dolomitic; crinoidal at the base. Chert never present.	450–1000	*SYRINGOTHYRIS*-ZONE. C *Syringothyris* aff. *cuspidata* mut. C.	(WAULSORTIAN PHASE.)
LOWER STRATIFIED LIMESTONE. Thick cherty zone at the summit, underlain by thinly-bedded dark-blue or grey fetid argillaceous limestones, in which chert may occur but is never abundant.	600–750	(horizon γ). *ZAPHRENTIS*-ZONE. Z_2 *Zaphrentis konincki* subzone.	TOURNAISIAN.
LOWER LIMESTONE SHALES. Interbedded black shales and limestones, the latter often crinoidal. Sandy shales and yellow sandstone at the base.	150	Z_1 *Spirifer* aff. *clathratus* subzone. *Cleistopora* Zone (?) (*Modiola* Phase.)	

[1] According to Dr. Wheelton Hind, these beds, which contain *Posidoniella lævis*, *Glyphioceras reticulatum*, *Pterinopecten papyraceus*, etc., are homotaxial with some part of the British Pendleside Series; but *Posidonomya becheri* and *Prolecanites compressus*, which characterize the lowest beds of the Pendleside Group, have not yet been recorded from County Clare.

Fig. 3.


OUTCROP OF
CARBONIFEROUS LIMESTONE
IN THE
COUNTY OF CLARE.
Scale of English Miles
0 2 4 6 8 10
Newer Rocks.
Viséan
Tournaisian
Older Rocks.
ARAN
ISLANDS
GALWAY BAY
Black Head
Ballyvaghan
Slieve Elva
Slievecarran
BURREN
Corranroo
Ardrahan
GALWAY
Aughty Mts.
Lough Derg
TULLA UPPER
TULLA LOWER
Tomgraney
Tulla
Sl. Bernagh Mts.
Crusheen
EAST CLARE
Corrofin
R. Fergus
Inchiquin L.
BUNRATTY UPPER
ENNIS
Quin
Bushy Park House
Newmarket on Fergus
Sixmilebridge
BUNRATTY LOWER
Bunratty
Cratloe
LIMERICK
O'Garney R.
R. Fergus
SHANNON
Liscannor Bay
WEST CLARE
ISLANDS
Kilrush
RIVER
KERRY
Loop Head
Long. West 9° of Greenwich

resistance to weathering; not to any essential difference of lithological character, such as the presence of argillaceous beds. If the latter were present to the extent of having this marked effect on the scenery, springs would be far more numerous than they are, and the terraces would be clothed with vegetation. The few springs which do occur are for the most part situated at the foot of the cliffs in fertile valleys, not on the barren terraced slopes.

Fig. 4.—*Terrace in the limestone-escarpment: Burren (Clare).*

J. A. D. photogr.

[The foreground shows the nature of the surface of a terrace.]

The best idea of this elevated plateau is obtained by driving from Ardrahan, in County Galway, to Ballyvaghan. For 10 miles or so the road traverses a limestone-plain, but near Aughinish Bay and the village of Corranroo, just at the boundary between the counties of Galway and Clare, the great eastern escarpment is first met with, rising suddenly to over 1000 feet (Slieve Carran, 1073 feet) and stretching far to the south in an almost unbroken line. The road is continued westwards along the foot of the northern escarpment; the latter, though somewhat more indented and irregular in outline than the eastern escarpment, is by no means less remarkable. Extending far inland, it forms the steep sides of the Turlough Valley, sweeps round Moneen Mountain and

Ballyconreagh, and again passes inland forming the huge amphitheatre of Ballyvaghan. This is a magnificent dry valley, bounded on three sides by steep terraced cliffs, and opening to the north on Galway Bay.

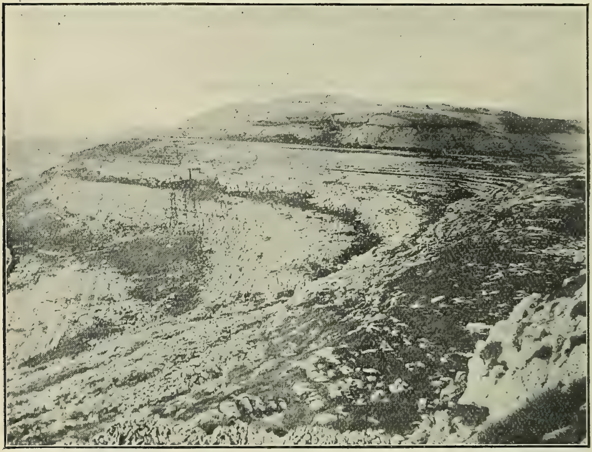
Fig. 5.—*Foot of the main escarpment, showing scree-formation: Burren (Clare).*

J. A. D. photogr.

The insignificant Rathborney River disappears underground at its southern end, and flows to the sea by a subterranean course (see footnote, p. 539). The escarpment then forms the southern shore of the bay as far as the conspicuous promontory of Black Head, which a short distance inland rises to over 1000 feet. Here it turns southwards, and dipping down to sea-level, passes beneath the Coal Measures [1] near Fisherstreet. This western margin is interrupted by the valley of the Caher River between Slieve Elva and Black Head.

[1] These beds have been shown by Dr. Wheelton Hind (*op. cit.*) to be the homotaxial equivalents of the Pendleside Series and the Millstone Grit.

Fig. 6.—*Natural limestone amphitheatre of Ballyvaghan (Clare).*



E. R. L. photogr.

Fig. 7.—*Eastern edge of the Burren plateau, showing the sudden rise from the central plain: Glencolumbkille (Clare).*

J. A. D. photogr.

Turning again to the eastern edge of the plateau, the main escarpment can be followed southwards, from Slieve Carran and Eagle's Rock, a magnificent vertical cliff 500 feet high, past the remarkable valleys of Glencolumbkille and Glenquin, to the north-west of Inchiquin Lough, near Corrofin. The successive terraces which build up these escarpments are well shown in the hills east of Glencolumbkille. The beds to the immediate south of this neighbourhood undulate considerably to the north-west and south-east, being well exposed on the outlying hill of Mullagh More.

The major features of this extensive plateau are repeated on a smaller scale over the whole of its surface, and many remarkable examples may be observed of more or less circular depressions and deep valleys surrounded on every side by steep terraced rock-faces. No wilder or more desolate spot can be found in the British Isles, and well does it deserve the name of Burren (b o r r = great, o n n = a stone or rock).

From the eastern escarpment to the border of the county stretches a broad limestone plain covered by numerous lakes. This low ground never rises above 200 feet, and has a mean altitude of 100 feet.

The southern district presents a totally different aspect. The limestone no longer forms a prominent topographical feature, but occupies all the low-lying ground in the centre of the county; while the high ground is formed, on the west by Coal Measures, and on the east by Old Red Sandstone and Silurian rocks. These older formations appear in two large anticlinal flexures with a north-easterly trend, forming the mountains of Slieve Aughty and Slieve Bernagh, between which lies a broad syncline of Carboniferous Limestone. The outer margin of this syncline is formed by Lower Limestone and Shales (Tournaisian), the successive zones of which can be traced continuously round its outcrop, while the Viséan or Upper Limestones occupy the core. All these beds are more or less strongly folded, the dips, though varied by minor flexures, as a rule following the general trend of the syncline.

The structure of the country, which is thus comparatively simple, is, however, greatly obscured by a covering of Drift, chiefly composed of limestone-débris from the underlying rocks. This central limestone area has a mean altitude of 150 feet, but reaches sea-level along the estuary of the Shannon. It rises to 300 feet in the neighbourhood of Tulla, and also to the west of Ennis, where it forms conspicuous rocky crags beneath the abrupt Coal-Measure escarpments. The drainage is effected, to the south by means of the Fergus and Owengarney Rivers and their tributaries, which flow into the Shannon; and to the east by the Graney River and other minor streams flowing into Lough Derg.

Lower Limestone beds are again met with, on the south-eastern slopes of the Slieve Bernagh Mountains, in the district north of Limerick.

IV. Generalized Description of the Faunal Succession.

Tournaisian or Lower Carboniferous Limestone.

M = *Modiola* Phase.

Lithological characters.—Thinly-bedded yellow sandstones.

Faunal characters.—These beds contain a rich lamellibranch-fauna, but no brachiopods characteristic of the succeeding zone have been recorded.

Dr. Wheelton Hind has kindly examined the lamellibranchs obtained from these beds; he reports that they have a 'very Silurian look', but may be similar to those occurring at the base of the Carboniferous at Pinskey Gill in Westmorland. They may probably be referred to *Grammysia* and *Modiolopsis*.

It has been suggested by Dr. Vaughan that the presence of this *Modiola* Phase, at the base of the Carboniferous Limestone Series, indicates a conformable transition from the underlying Old Red Sandstone. This point is of considerable interest, for the small thickness and faunal characters of the *Cleistopora* Zone in this district would suggest an unconformity. Throughout the whole of County Clare, however, the exposures in these beds are so poor, that there can be said to be no conclusive evidence.

K = Zone of *Cleistopora* aff. *geometrica* (Cleistopora Zone).

Lithological characters.—Olive-green and yellow sandy shales.

Former designation.—Sandy basement-beds of the Lower Limestone Shales.

Faunal list:—

[1] *Orthotetes crenistria* (Phill.) mut. K_1.
Leptæna cf. *analoga* (Phill.).
Chonetes laguessiana, de Kon.
Spiriferina octoplicata (Sow.).
Productus cf. *bassus*, Vaughan.
Productus sp. [precursor of *Pr. pustulosus*, Phill.].
Camarotœchia mitcheldeanensis, Vaughan.
Eumetria aff. *carbonaria* (Dav.).
Rhynchonella cf. *acutirugata*, de Kon.
Reticularia reticulata, M'Coy.

Special faunal characters:—

The beds included in this zone have a thickness of not more than 20 feet. They contain an assemblage of brachiopods characteristic of the *Cleistopora* Zone, but a further division into subzones was not found practicable.

The zonal index *Cleistopora* aff. *geometrica* has not been recorded, but *Spiriferina octoplicata* and a bassiform *Productus*, the subzonal

[1] To avoid confusion, I have adhered for the most part to the terminology used in Dr. Vaughan's paper on the Bristol area, although certain genera, such as *Orthotetes*, *Chonetes*, *Spiriferina*, etc., are now undergoing revision.

For reference to the work of Mr. R. G. Carruthers on the Tournaisian corals, see under the heading 'Correlation,' § VI, p. 564.

indices of the Bristol area, are of common occurrence throughout. *Leptæna* cf. *analoga*, *Orthotetes crenistria* in a characteristic mutation, and a small *Chonetes* with very fine ribbing (cf. *Chonetes laguessiana*, de Kon.) are abundant. *Eumetria*, *Camarotœchia*, and *Reticularia* occur sparingly.

Z = Zone of *Zaphrentis omaliusi* (ZAPHRENTIS Zone).

The lithological characters are dealt with in the description of the subzones.

Former designation.—Lower Limestone Shales and Lower Stratified Limestone.

Z_2 = subzone of *Zaphrentis konincki*.
Z_1 = subzone of *Spirifer* aff. *clathratus*.

Faunal list:—

Corals:

Zaphrentis omaliusi, M.-Ed. & H. and var. *densa*, Carruthers.
Zaphrentis konincki, M.-Ed. & H.
Zaphrentis vaughani, sp. nov.
Caninia cornucopiæ, Mich.
Campophyllum cylindricum (Scouler) [= *Caninia*].
Syringopora 'θ' of Vaughan.
Michelinia favosa (Goldf.).
Cyathophyllum patula, Mich.

Brachiopods:

Spirifer aff. *clathratus*, M'Coy, Vaughan.
Spiriferina cf. *octoplicata* (Sow.).
Athyris lamellosa (L'Éveillé).
Athyris cf. *glabristria* (Phill.).
Rhipidomella michelini (L'Éveillé, Dav.).
Schizophoria aff. *resupinata* (Mart.).
Syringothyris aff. *cuspidata* (Mart.) mut. Z.
Syringothyris laminosa (M'Coy).
Orthotetes crenistria muts. (Phill.).
Chonetes cf. *hardrensis*, Phill.
Chonetes cf. *crassistria* (M'Coy).
Reticularia cf. *reticulata*, M'Coy.
Derbya bristolensis, Vaughan.
Productus aff. *pustulosus*, Phill.
Leptæna cf. *analoga* (Phill.).
Productus cf. *burlingtonensis*, Hall.
Productus aff. *semireticulatus* (Mart.).

Other groups:

Phillipsia gemmulifera (Phill.).
Phillipsia truncatula (Phill.).
Actinocrinus polydactylus (Miller) and other crinoid-stems.
Palatal teeth of fishes.
Fenestella sp.

Subdivisions:—

Horizon β.

The only indication of this horizon of faunal overlap is the co-occurrence of *Zaphrentis* and *Spiriferina* cf. *octoplicata* at the base of the Lower Limestone Shales. Exposures are very poor, and the evidence is far from satisfactory.

Athyris lamellosa occurs commonly in these beds; a form which is characteristic of the '*octoplicata* subzone' (K_2) in the Mendip area.

Z_1 = Subzone of *Spirifer* aff. *clathratus* (CLATHRATUS subzone).

Lithological characters.—Dark-grey and black shales, with occasional bands of crinoidal limestone; chert-bands rare.

Special faunal characters:—

A densiphylloid *Zaphrentis* is extremely abundant at the base, where it is associated with *Productus* cf. *burlingtonensis* and *Syringothyris cuspidata* in a characteristic mutation.

Syringopora θ is rare; no other corals have been recorded.

Spirifer aff. *clathratus* and *Rhipidomella michelini* attain their maxima in this subzone.

Leptæna analoga, *Reticularia* cf. *reticulata*, *Athyris lamellosa*, and *Orthotetes crenistria* mut. are common at certain levels.

Spiriferina cf. *octoplicata* and *Derbya bristolensis* are represented by single specimens.

Z_2 = Subzone of *Zaphrentis konincki*.

Lithological characters.—Compact dark-blue and black, thinly-bedded limestones with shaly partings, which become more persistent towards the base.

The bedding is in places obscured by a strongly developed cleavage.

Chert is abundant throughout this subzone, and a well-defined cherty band about 40 feet thick forms a noticeable and constant feature at the summit.

Special faunal characters:—

Zaphrentis konincki enters at the base, and becomes enormously abundant at the summit, where it is associated with *Caninia cornucopiæ* and *Campophyllum cylindricum*.

Michelinia favosa and *Syringopora* θ range throughout.

Trilobites and fish-teeth occur frequently in the cherty beds.

Syringothyris aff. *cuspidata* and *Chonetes hardrensis* crowd certain shaly beds near the base.

Orthotetes crenistria, in a characteristic mutation, and *Leptæna analoga* are common.

Schizophoria resupinata enters but is never abundant, and *Syringothyris laminosa* is rare.

Spirifer aff. *clathratus* is still common at certain levels.

A characteristic pustulose *Productus* is abundant.

Horizon γ.

Strictly speaking, there is no horizon of faunal overlap between this and the succeeding zone, for the incoming of the latter is marked by a more or less complete change of fauna, indicating a sudden change of bathymetrical conditions. Since, however, in the top beds of the *Zaphrentis* Zone, *Zaphrentis konincki* and *Campophyllum cylindricum* occur together in some abundance, a correlation may be made with horizon γ of the Bristol area.

C = Zone of *Syringothyris cuspidata* mut. C (SYRINGOTHYRIS Zone).

Former designation.—Lower Unstratified or *Fenestella* Limestone.

Lithological characters.—Massive limestones, with a characteristic dark-grey and white mottled coloration, often assuming the aspect of marble.

The rock is, in many exposures, crowded with the remains of bryozoa, the cross-sections of which give it a peculiar spotted appearance. The interiors of molluscan and brachiopod shells are usually filled with pure white crystalline calcite. Bedding is rarely visible, except in a pale-grey crinoidal band near the base.

The limestone is often magnesian, and becomes a true dolomite of a yellowish colour at the summit.

Chert is never found in this zone.

Faunal list:—

Brachiopods:

Syringothyris cuspidata (Mart.).
Spirifer (Brachythyris) pinguis, Sow.
Spirifer (Brachythyris) ovalis, Phill., and var. *hemispherica*, M'Coy.
Spirifer aff. *clathratus*, M'Coy, Vaughan.
Spirifer attenuatus, J. de C. Sow.
Spirifer subcinctus, de Kon.
Spirifer konincki, sp. nov.
Pugnax reniformis (Sow.).
Pugnax pugnus (Mart.).
Schizophoria resupinata (Mart.)
Dielasma hastatum (J. de C. Sow.).
Dielasma kingi, de Kon.
Productus aff. *semireticulatus* (Mart.).
Productus cf. *concinnus* (Sow.).
Productus aff. *quincuncialis*, Phill., mut. C.
Productus cora, D'Orb., mut. C.
Productus plicatilis, Sow.
Athyris aff. *glabristria* (Phill.).
Athyris hibernica, nom. nov.
Leptæna cf. *analoga* (Phill.).
Athyris planosulcata (Phill.).
Spiriferina cf. *insculpta* (Phill.).

Corals:

Amplexus coralloides, Sow.

Mollusca:

Vestinautilus carinifer (J. de C. Sow.).
Trigonoceras paradoxicum (J. de C. Sow.)
Solenocheilus dorsalis (Phill.).
Apheleceras mutabile (M'Coy).
Glyphioceras sphæricum (Martin).
Orthoceras leinsterense, Foord.
Asymptoceras sp., Ryckholt.
Poterioceras fusiforme (J. de C. Sow.).
Euomphalus pentangulatus, J. Sow.
Euomphalus cf. *latus*, Hall.
Loxonema lefebvrei (L'Eveillé).
Naticopsis plicistria (Phill.).
Naticopsis aff. *phillipsi*, M'Coy.
Cardiomorpha egertoni (M'Coy).
Cardiomorpha oblonga (J. de C. Sow.).
Edmondia lyelli, Hind.
Conocardium hibernicum, Sow.
Sanguinolites omalianus (de Kon.).
Aviculopecten plicatus, Sow.

Crinoids:

Actinocrinus tessellatus (Phill.).

Bryozoa:

Fenestella multiporata, M'Coy, and other species.
Ichthyorachis cf. *newenhami*, M'Coy.[1]

Special faunal characters:—

The remarkable and sudden change in the lithological character of these beds is accompanied by the incoming of a perfectly distinct fauna, of which not more than half-a-dozen species pass up from the beds below. The numerous and varied corals of the *Zaphrentis* Zone have here disappeared, and are replaced by a luxuriant molluscan fauna. The abundance of large-sized individuals, both among the mollusca and brachiopoda, seems to indicate a change to relatively shallow-water conditions. The nature of the rock points to rapid deposition[2]; and the absence of corals, with the exception of *Amplexus*, may be possibly thus accounted for; the essentially tabulate character of this genus suggests the power of rapid growth, which alone would enable it to survive these adverse conditions.

In this district the rocks are disturbed by minor flexures, and as they are only visible in isolated exposures, it is impossible in the absence of stratification to determine the exact range of individual species throughout the zone; the faunal assemblage, however, in nearly every exposure was found to be identical.

The zone is characterized by the great abundance of *Amplexus coralloides*, which is the only coral recorded. The zonal index, *Syringothyris cuspidata*, here reaches the acme of its development, attaining an immense size compared with specimens from lower beds. It is never abundant however, and *Syringothyris laminosa* has not been recorded. *Spirifer clathratus* is still represented, but in diminished numbers, whereas *Spirifer attenuatus*, *Spirifer pinguis*, and *Spirifer ovalis* are abundant. *Spirifer subcinctus* is of frequent occurrence.

Pugnax reniformis, *Athyris* aff. *glabristria*, *Dielasma hastatum*, and *Productus semireticulatus* are also common.

Productus aff. *quincuncialis* and *Productus* cf. *concinnus* are widely distributed, but never abundant.

Schizophoria resupinata here exhibits its typical characters, but is rare. The other brachiopods mentioned in the faunal list occur sparingly.

The abundance of mollusca, of which the cephalopod *Vestinautilus carinifer* is the most prolific, forms one of the distinguishing features of the zone.

[1] The above represents a very incomplete list of the prolific fauna obtainable from this zone, but I was unfortunate to be working these beds when the quarries had been cleared and most of the material had been broken up as road-metal. Mr. Walsh, the schoolmaster at Cratloe, near Limerick, has however a large collection, and I have to thank him for several of my specimens.

[2] The lamellibranchs, as a rule, preserve their two valves intact, so there cannot have been much transportation.

The most abundant forms are *Apheleceras mutabile*, *Conocardium hibernicum*, *Cardiomorpha egertoni*, and *Euomphalus pentangulatus*, but many of the others mentioned are hardly less important.

The abundance of bryozoa has been already noted; these belong chiefly to the genus *Fenestella*.

Viséan or Upper Carboniferous Limestone.

S = Zone of *Seminula ficoides* and its allies (SEMINULA Zone).

Former description.—Lower part of Upper Limestone; the 'Calp' Limestone of other districts is not recognized in County Clare.

Lithological characters.—These beds vary considerably in character in different parts of the county. At the base occur dark-grey limestones with an abundance of chert, above which there is often an impure dolomite.

Towards the centre of the zone, black compact crinoidal limestones are succeeded by oolitic beds, which in some localities contain pebbles of a considerable size. Pale-grey limestones of a finely crystalline texture form a characteristic feature near the summit.

Faunal list:—

Corals:

Campophyllum cylindricum (Scouler) mut. S_1 [= *Caninia*].
Zaphrentis omaliusi, M.-Ed. & H., var. *densa*, Carruthers.
Zaphrentis aff. *enniskilleni*, M.-Ed. & H.
Campophyllum cf. *caninoides*, Sibly.
Carcinophyllum aff. *mendipense*, Sibly.
Carcinophyllum sp.
Michelinia grandis, M'Coy.
Cyathophyllum aff. *murchisoni* (M.-Ed. & H.).
Lithostrotion martini, M.-Ed. & H.
Nematophyllum minus, M'Coy.
Syringopora reticulata, Goldf.
Syringopora geniculata, Phill.
Syringopora cf. *ramulosa*, Goldf.
Early Clisiophyllids.

Brachiopods:

Productus cora, d'Orb., mut. S_2.
Productus aff. θ of Vaughan.
Productus punctatus (Mart.).
Productus elegans, M'Coy.
Productus cf. *semireticulatus* (Mart.).
Productus pustulosus, var. *ovalis*, Phill.
Daviesiella cf. *comoides* (Sow.).
Chonetes papilionacea, Phill.
Orthotetes aff. *crenistria* (Phill.).
Seminula ambigua (Sow.).
Dielasma aff. *hastatum* (Sow.).
Camarophoria isorhyncha, M'Coy.

S_1 = Subzone of *Productus* cf. *semireticulatus* mut. S_1 (SEMIRETICULATUS subzone).

Special faunal characters:—

This subzone is characterized by the incoming of a typical Viséan fauna, including the earliest Clisiophyllids and *Lithostrotion*.

Corals:

Carcinophyllum aff. *mendipense* enters at the base, where it is associated with *Campophyllum cylindricum* mut. S_1. The latter here attains its second maximum, and is enormously abundant locally.

Lithostrotion martini occurs commonly throughout, appearing in some localities at the base, in others being absent or extremely rare at this level.

Syringopora geniculata becomes increasingly important, but *S. reticulata* is restricted to the lower part.

Michelinia grandis and *Zaphrentis omaliusi* var. *densa* occur locally at the base, but are never common.

Campophyllum cf. *caninoides* is rare.

Brachiopods:

Daviesiella cf. *comoides* is abundant in the lower part.

Productus punctatus and var. *elegans* are not uncommon.

Productus aff. θ occurs sparingly.

Camarophoria isorhyncha is locally common.

Productus cf. *semireticulatus* is nowhere abundant.

Orthotetes aff. *crenistria* is of common occurrence near the base.

S_2 = Subzone of *Productus* aff. *cora* mut. S_2 (CORA subzone).

Special faunal characters:—

Corals:

Nematophyllum minus is enormously abundant near the summit, forming a well-marked horizon; it is associated with *Carcinophyllum* sp., which genus attains its maximum at this level.

Syringopora geniculata and *S. ramulosa* are common, especially in the topmost beds.

Lithostrotion martini is abundant throughout.

Cyathophyllum aff. *murchisoni* occurs sparingly, but is never common.

Zaphrentis aff. *enniskilleni* was recorded from the summit of this zone.

Brachiopods:—

Productus aff. *cora* mut. S_2 is very abundant locally.

Dielasma aff. *hastatum* and *Seminula ambigua* are common in the topmost beds. *Chonetes papilionacea* occurs sparingly. All the other brachiopods mentioned in the faunal list are rare.

The oolitic beds mentioned above are, in some localities, crowded with gastropods, the commonest genera being *Loxonema*, *Euomphalus*, and *Straparollus*.

A characteristic bryozoan in this subzone is *Hemitrypa*.

D = Zone of *Dibunophyllum* aff. *turbinatum* (DIBUNOPHYLLUM Zone).

Lithological characters.—It is hardly possible to record any definite lithological characters in this zone, as the rocks attain a thickness of over 1500 feet, and vary considerably throughout the county. In the northern or Burren district, from which most of the fossils were collected, the limestone at the base is usually dark grey and very crinoidal, thinly bedded, and argillaceous; it becomes magnesian locally, and contains an abundance of chert. Higher up, the beds vary in thickness from a few inches to several feet; the limestone is here usually much purer, and is often pale grey and of a finely crystalline texture; chert is rare.

Near the summit occurs locally a compact black limestone, in which chert is found as well-defined bands; above this, and immediately followed by the black shales of the Pendleside Series, the rock is built up almost entirely of crinoidal fragments, and contains small patches and veins of dolomite.

Former designation.—Upper or Burren Limestone.

Subzones:
- D_3, subzone of *Cyathaxonia rushiana.*
- D_2, subzone of *Lonsdalia floriformis.*
- D_1, subzone of *Dibunophyllum* θ, ϕ.

Faunal list:—

Corals:

Alveolites septosa (Flem.).
Syringopora geniculata, Phill.
Lithostrotion martini, Ed. & H.
Lithostrotion irregulare (Phill.).
Lithostrotion junceum (Flem.).
Lithostrotion affine (Flem.).
Lithostrotion portlocki (Bronn).
Diphyphyllum subibicinum (M'Coy).
Clisiophyllid *Lithostrotion.*
Lonsdalia duplicata (Mart.).
Dibunophyllum θ of Vaughan.
Dibunophyllum aff. *muirheadi*, Thoms. & Nich.
Dibunophyllum aff. ψ, Vaughan.
Carcinophyllum sp.
Campophyllum aff. *marginatum*, Thoms.
Cyathophyllum murchisoni, Ed. & H.
Cyathophyllum regium, Phill.
Cyclophyllum sp.
Zaphrentis enniskilleni, Ed. & H.
Zaphrentis oystermouthensis, Vaughan MS.
Densiphyllum cf. *rushianum*, Vaughan.
Densiphyllum sp.
Caninia aff. *cornucopiæ*, Mich.

Brachiopods:

Productus giganteus (Mart.) and allied forms.
Productus hemisphericus, Sow.
Productus striatus (Fischer).
Productus '*corrugato-hemisphericus*,' Vaughan.
Productus cf. *corrugatus*, M'Coy.
Productus punctatus (Mart.).
Productus cf. *elegans*, M'Coy.
Productus aff. *scabriculus* (Mart.).
Productus sulcatus, Sow.
Productus aff. *concinnus*, Sow.
Athyris expansa (Phill.).
Athyris planosulcata (Phill.).
Daviesiella aff. *comoides* (Sow.).
(Papilionaceous) *Chonetes* cf. *compressa*, Sibly.
Chonetes cf. *hardrensis*, Phill.
Seminula ambigua (Sow.), mut. D_1.
Martinia glabra (Mart.).
Reticularia lineata (Dav.).
Spirifer aff. *increbescens*, Hall.
Cyrtina septosa (Phill.).
Dielasma aff. *virgoides* (M'Coy).
Dielasma cf. *ficus* (M'Coy).

D_1 = Subzone of *Dibunophyllum* θ and ϕ (θ, ϕ subzone).

Special faunal characters:—

Corals:

The simple Clisiophillids, such as *Dibunophyllum* θ and *D. muirheadi*, are abundant throughout this subzone.

Carcinophyllum sp. is common at the base, where it is associated with Clisiophyllid *Lithostrotions*.

Lithostrotion martini is still abundant, but becomes replaced by *L. irregulare*.

Lithostrotion affine occurs commonly near the base, and *L. junceum* makes its appearance towards the summit.

Alveolites septosa is also common at this level.

Syringopora geniculata is rare, except near the base.

Cyathophyllum murchisoni is prolific at certain levels.

Brachiopods:

Productus aff. *giganteus* is abundant, but the typical form of this species has not been recorded. A small form of *Pr. punctatus* is very characteristic of this subzone, but *Pr. hemisphericus* is never common.

Daviesiella aff. *comoides* occurs sparingly.

Seminula ambigua mut. D_1, *Dielasma* aff. *virgoides*, *D.* cf. *ficus*, *Athyris planosulcata*, and *Reticularia lineata* are all of common occurrence, especially near the base.

One of the most characteristic features of this subzone in County Clare is the abundance of large *Euomphali* of the type of *Euomphalus acutus*.

D_2 = Subzone of *Lonsdalia floriformis* (*Lonsdalia* subzone).

Special faunal characters:—

Corals:

Lonsdalia duplicata is abundant near the summit, but *L. floriformis* has not been recorded.

Dibunophyllum, near ψ, is the only other common Clisiophyllid; but this is of local occurrence.

Cyathophyllum regium is common.

Lithostrotion junceum and *L. irregulare* are abundant.

Alveolites septosa and *Syringopora* cf. *geniculata* are rare.

Campophyllum sp., *Carcinophyllum* sp., and *Diphyphyllum subibicinum* occur locally near the base.

Brachiopods:

Productus giganteus reaches the acme of its development, and *Pr. striatus* and *Pr. 'corrugato-hemisphericus'* are locally abundant.

Cyrtina septosa is common in certain localities, and has not been recorded outside this subzone.

Athyris expansa and *Chonetes* cf. *hardrensis* occur sparingly.

D_3 = Subzone of *Cyathaxonia rushiana* (CYATHAXONIA subzone).

Special faunal characters:—

The Clisiophyllids and Lithostrotions are typically absent, and are replaced by Zaphrentids of the type of *Zaphrentis enniskilleni* and *Z. oystermouthensis*; *Caninia* aff. *cornucopiæ* is everywhere common. No specimen of *Cyathaxonia* has yet been recorded.

Productus aff. *scabriculus* and *Pr. punctatus* are found here.

Martinia glabra, *Athyris expansa*, and *Spirifer* aff. *increbescens* have been recorded, but the most characteristic brachiopod is *Productus sulcatus*.

V. Description of certain Fossil Localities.

(A) Barony of Lower Bunratty.

Lower Limestone Shales (*Modiola* Phase to lower part of Z_2).—These beds occur along the north-western foot of the Slieve Bernagh Mountains, but are everywhere covered by Drift except in the Gourna River section: the latter is a small tributary of the Owengarney, about a mile east of Sixmilebridge. The section commences at Ballyroe Bridge, where beds of unfossiliferous green shales and sandstones, belonging to the Old Red Sandstone Series, are seen. About 100 yards down stream occurs a prominent band of hard blue grit, and immediately above this the basement-beds of the Carboniferous are met with, consisting of a few feet of thinly-bedded yellow sandstones, which contain a rich lamellibranch fauna (the *Modiola* Phase). They are succeeded by shaly sandstones of the *Cleistopora* Zone; all the fossils mentioned in the faunal list (K) were found at this locality. The stream at this point takes a bend, following the strike of the beds; and as the latter are only exposed in a few feet of overhung bank, their conformability with the underlying Old Red Sandstone is difficult to prove. These sandy beds cannot be directly measured, but their thickness probably does not exceed 20 feet. They are overlain conformably by the black fossiliferous shales of the *clathratus* subzone (Z_1), which are here especially rich in fossils (*Syringothyris* aff. *cuspidata*, *Rhipidomella michelini*, *Productus* cf. *burlingtonensis*, *Zaphrentis* sp.). These beds can be followed for some distance down stream, but soon become obscured by Drift, and are not exposed along the small stream-valley entering on the east.

When they are again met with, forming a small cascade in the main stream, several new species have made their appearance (*Zaphrentis konincki*, *Michelinia favosa*, *Syringopora* θ), and interbedded limestone-bands become more persistent. I regard these beds as forming the lowest exposure in the *konincki* subzone (Z_2). They crop out continuously almost as far as Gourna Bridge, the last

beds to be exposed being thin shales crowded with *Syringothyris* aff. *cuspidata* and *Chonetes* cf. *hardrensis*.

Lower Stratified Limestone (Z_2—γ).—These beds are best seen in the vicinity of Sixmilebridge. West of Oilmill Bridge there is a considerable tract of land free from Drift, in which are exposed dark-grey impure limestones, often highly cleaved.

These beds contain *Zaphrentis konincki*, *Caninia cornucopiæ*, *Michelinia favosa*, and *Camphophyllum cylindricum* in abundance, but brachiopods are not common. (Beautiful examples of weathered coral-calices can be obtained from this locality.) Several small quarries are also to be noted on the south-east of the road opposite the Roman Catholic chapel.

Somewhat similar beds are again seen in the Owengarney River section, north of Sixmilebridge. From Annagore Bridge they have an average dip of 15° to the north by west, as far as Ballymulcashel Bridge, south of Castle Lake. They are here highly fossiliferous, containing *Phillipsia gemmulifera*, *Spirifer* aff. *clathratus*, *Leptæna analoga*, *Syringothyris laminosa*, *Orthotetes crenistria*, *Chonetes* cf. *hardrensis*, *Athyris* cf. *glabristria*, *Caninia cornucopiæ*, and *Zaphrentis konincki*. At the top of the hill west of Ballymulcashel Bridge, they are seen to pass beneath the unbedded limestone of the *Syringothyris* Zone, and the cherty beds dividing the two zones may be traced far to the north-east.

Lower Massive Limestone (*Syringothyris* Zone).—These beds can be traced from Newmarket-on-Fergus north-eastwards beyond Kilmurry. They are more easily examined, however, in the neighbourhood of Cratloe, a small village about 4 miles north-west of Limerick, where they crop out along the south of the Slieve Bernagh anticline. The rock is here extensively quarried for road-metal, and is rich in fossils, of which the following are most abundant:—*Vestinautilus carinifer*, *Solenocheilus dorsalis*, *Syringothyris cuspidata*, *Dielasma hastatum*, *Pugnax reniformis*, *Spirifer attenuatus*, *Sp. pinguis*, and *Sp. konincki*. The dolomite at the top of this zone is well exposed to the north of Cratloe Castle.

Upper Limestone (*Seminula* Zone).—Beds included in this zone crop out in bare tracts of rock over the northern part of the Barony. From Newmarket, or Ballycar Railway-station, which is situated on the cherty basement-beds, they can be followed up the western side of Fin Lough to the crags south of Lough Caherkine; here a black compact limestone, with *Lithostrotion martini*, *Productus punctatus*, and other common forms, is seen to pass into an oolite, which is crowded with gasteropods and contains small pebbles often measuring more than 2 centimetres in diameter.

(B) Barony of Upper Tulla.

Lower Limestone Shales (K—Z_2) and Lower Limestone (Z_2—γ).—These beds, when followed northwards from the Gourna River along the foot of the Slieve Bernagh Mountains, are found to be everywhere covered by Drift: the only exposure being that of the Anamullaghaun River, between Bodyke and Tomgraney. This section, though fully described in the Irish Geological Survey Memoir (Explanation of Sheet 133), is now almost entirely overgrown, and the junction with the Old Red Sandstone cannot be accurately determined. The following fossils were obtained from this locality:—*Spirifer* aff. *clathratus*, *Rhipidomella michelini*, *Orthotetes crenistria*, *Productus* cf. *pustulosus*, and *Zaphrentis omaliusi*, var. *densa*. These basement-beds are again seen south of the Roman Catholic chapel at Tomgraney, and their passage into the Lower Limestone is well shown, the lowest beds of the latter forming a conspicuous rocky knoll in the centre of the village.

Lower Massive or *Fenestella* Limestone (C).—Most of the country to the west of Bodyke is covered by esker-like mounds of Drift; but several isolated exposures are met with along the road to Tulla, which is built on the highest point of the central limestone plain. In the neighbourhood of this village the beds form extensive tracts of bare rock, and are quarried for road-metal. Between Tulla and Milltown Mine, which is situated on the junction between the stratified and the massive limestones, the rocks everywhere abound in fossils, the following being of common occurrence:—*Athyris* aff. *glabristria*, *Dielasma hastatum*, *Productus* aff. *quincuncialis*, *Euomphalus pentangulatus*, *Vestinautilus carinifer*, *Trigonoceras paradoxicum*, and *Fenestella multiporata*.

Upper Limestone, base (S_1).—The junction of the basement cherty beds of this zone with the mottled limestones below is well seen near Dangan Villa, north-west of Lough Cullaunyheeda, the beds having an average dip of 5° to the south-east. The intervening dolomite is also exposed, and can be traced almost continuously westwards to Ballyhickey Mine. The lowest beds are dark-grey, compact, crinoidal limestones with very few fossils; *Lithostrotion martini* enters at the base, and is associated with a large *Daviesiella* in the form of hollow casts.

(C) Baronies of Upper Bunratty and Islands.

The southern part of this district is occupied by Upper Limestone, forming the central core of the great east-to-west syncline, which is for the most part obscured by Drift and patches of bog.

Though extensive tracts of bare rock are of local occurrence, fossils are, as a rule, scarce.

South of Jasper's Bridge, 2 miles to the west of Quin, there is a considerable development of oolitic limestone, which seems to occur at a higher level than that previously mentioned at Caherkine Lough. Half a mile to the north, at Ballyglass House, lower beds are seen containing a great abundance of chert; the limestone is here crowded with the bryozoan *Hemitrypa.*

The following fossils were obtained from the district between Kilbreckan Mine and Ennis; *Lithostrotion martini*, *Cyathophyllum* sp., *Productus elegans*, papilionaceous *Chonetes*, and a small convex *Chonetes* cf. *hardrensis.*

The road from Tulla to Ennis for about the first 8 miles is situated on the Lower Massive Limestone, which everywhere abounds in fossils. The following were obtained from Sandhill Bridge:—*Amplexus coralloides*, *Productus semireticulatus*, *Dielasma hastatum*, *Productus* aff. *quincuncialis*, *Vestinautilus carinifer*, and *Fenestella* sp.

Near Castletown Lough the dolomite and the basement cherty beds of the Upper Limestone are met with, and from this point as far as Ennis there is a fairly constant westward dip: a feature due to the extension of the Slieve Aughty anticline. West of Ennis the Upper Limestone forms conspicuous rocky crags, beneath the Coal-Measure escarpment. The rocks consist for the most part of thickly-bedded, black and dark-grey, compact, crystalline limestones, with an abundance of chert at several horizons. A large quarry in the hill north of Inch Bridge affords an interesting exposure near the base of the *Lonsdalia* subzone. The following fossils are abundant at this locality:—*Productus giganteus*, *Pr. 'corrugato-hemisphericus'*, *Pr. striatus*, *Athyris expansa*, *Cyrtina septosa*, *Alveolites septosa*, *Syringopora* cf. *geniculata*, *Lithostrotion junceum*, *L. irregulare*, *Cyathophyllum regium*, and *Lonsdalia duplicata.* (The two last-mentioned forms occur near the summit of the hill, but are apparently absent in the quarry.)

Farther north, near Bushy Park House, still higher beds are met with. These contain *Zaphrentis enniskilleni*, *Z. oystermouthensis*, *Densiphyllum* sp., *Caninia* aff. *cornucopiæ*, *Productus punctatus*, *Pr. sulcatus*, and *Athyris expansa*, and are taken as representative of the D_3 subzone.

In a field west of the road leading down to Shallee Castle is a dripping well, in which is exposed the junction between the limestone and the overlying shales.

(D) Barony of Inchiquin and the northern half of Upper Bunratty.

In this central area the outcrop of the limestone narrows to its smallest limits, and the complete succession can be traversed from

Crusheen on the east to Corrofin on the west, although the country is covered to a large extent by lakes and superficial Drift-deposits.

The lowest beds, which occur along the north-western foot of the Slieve Aughty Mountains, are for the most part obscured by esker-like mounds of Drift, but the shales of the *clathratus* subzone are visible in one or two localities in the neighbourhood of Doon Lough. The *konincki* subzone is also poorly exposed, but its junction with the *Syringothyris* Zone, which here shows traces of stratification, is visible about 200 yards north of Inchicronan Lough, the intervening cherty beds being strongly developed. The following fossils were found at this locality:—*Syringothyris cuspidata, Spirifer konincki, Productus semireticulatus, Pr.* aff. *quincuncialis*, and *Amplexus coralloides.*

The district to the south along the Ennis road abounds in fossils, of which *Vestinautilus carinifer, Apheleceras mutabile, Pugnax reniformis, Productus semireticulatus*, and *Amplexus coralloides* are the most abundant.

The small patch of country to the east of the bog near Curraderra Lough, coloured on the Geological Survey map as Upper Limestone, was found to contain *Zaphrentis konincki, Z. omaliusi, Caninia cornucopiæ, Campophyllum cylindricum*, and *Michelinia favosa*, an assemblage of corals characteristic of the top of the *Zaphrentis* Zone; and it is probable that the cherty beds which occur at this level were mistaken for those at the base of the Upper Limestone.

About a mile north-west of Crusheen is exposed an extensive tract of bare limestone, which stretches far to the north and west. The rock is here dark-grey, compact, and crystalline, and is quarried for building purposes. To the west of Garlick Hill the contained fossils indicate a Lower *Seminula* age, the following being abundant at this locality:—*Campophyllum cylindricum* mut. S_1, *Syringopora reticulata, Michelinia grandis*, early Clisiophyllids, and *Daviesiella* cf. *comoides.* The beds to the westward undulate considerably; and, though south of Moyree Castle *Dibunophyllum* is of common occurrence, the *Seminula* Zone is again met with in the neighbourhood of Lough Nabrickoge: *Productus cora* mut. S_2, papilionaceous *Chonetes, Seminula ambigua, Carcinophyllum*, and *Lithostrotion martini* being the most abundant fossils. From this point as far as Corrofin the rocks contain a fauna characteristic of the *Dibunophyllum* Zone, the district between Loughs Cullaun and Inchiquin being especially rich in fossils, such as *Dibunophyllum muirheadi, D.* θ, *Cyathophyllum murchisoni, Lithostrotion junceum, L. martini*, and *Productus* aff. *giganteus.* No fossils characteristic of the *Lonsdalia* subzone were recorded from this neighbourhood; but the topmost beds of the limestone were found to contain *Zaphrentis enniskilleni, Caninia* aff. *cornucopiæ, Densiphyllum* and *Productus* cf. *scabriculus*, while the overlying black shales were crowded with goniatites and other

fossils.[1] The latter beds, which Dr. Wheelton Hind has shown to be the equivalents of the Pendleside Series, crop out along the conspicuous escarpment to the west of Inchiquin Lough. Chert is very abundant in the Upper Limestone Beds of this locality, occurring in continuous well-defined bands, one of which forms the summit of Slate Island in the centre of the Lough.

(E) Barony of Burren.

Nearly the whole of the Barony of Burren, which lies in the extreme north of the county, is formed by a vast elevated plateau of Upper Limestone, rising on the west, north, and east in steep terraced cliffs and dipping gently to the south and south-west beneath the Coal Measures.

The thickness of limestone visible above sea-level amounts to about 1500 feet; and, as the beds undulate considerably, though the dip rarely exceeds 5°, it is almost impossible to trace their stratigraphical sequence over this large area, the bare surface of rock which it presents being too vast to admit of the detailed work necessary for accurate zoning. It is possible, however, by following a definite line across the country, to identify the zones and trace them within certain limits; but to map their extension over the whole area would entail many years of arduous work, and the results would hardly repay the time expended.

The district of Oughtmama in the extreme north, between the bays of Aughinish and Muckinish, is almost completely covered by Drift, and the lowest visible beds occur farther south, from the foot of Ballyconreag, along the southern shore of Ballyvaghan Bay, as far as the promontory of Black Head. These beds were found to contain a fauna characteristic of the S_2 subzone, the profusion of *Nematophyllum minus* at one horizon being a conspicuous local feature; other fossils recorded from these beds were:—*Carcinophyllum* sp., *Syringopora geniculata*, *Campophyllum* sp., *Lithostrotion martini* and *L. affine*, *Seminula ambigua*, *Dielasma* aff. *hastatum* and *Chonetes papilionacea*.

Passing inland, attention was chiefly directed to the investigation of a section drawn slightly east of south from Lough Rask (an interesting inland tidal lake) past Wood Village and Ballyallaban House, and another from Acres Village over Moneen Mountain. An examination was also made of the district to the west comprised in the townland of Gleninagh, including Black Head and the western shore-line. The following description, however, deals chiefly with the first section.

[1] The following fossils were obtained from this locality:—*Orthoceras steinhaueri*, Sow., *Myalina peralata*, de Kon., *Glyphioceras reticulatum*, Phill. *Posidoniella lævis*, Brown, and plant-remains.

The S_2 subzone seems to extend about a mile inland from the shore-line; but the comparative scarcity of fossils renders it a matter of some difficulty to locate the approximate base of the *Dibunophyllum* Zone. The floor of the Ballyvaghan amphitheatre, which has a gradual slope up to about 250 feet, is formed by somewhat impure limestone-beds yielding the following D_1 fossils:—*Dibunophyllum muirheadi, Lithostrotion irregulare*, Clisiophyllid *Lithostrotion, Productus* 'aff. *giganteus*', *Pr.* aff. *hemisphericus, Pr.* cf. *elegans, Daviesiella* aff. *comoides, Reticularia lineata*, and *Athyris planosulcata.*

A well marked horizon of chert occupies the base of the two rather prominent spurs which jut out from the foot of the main escarpment.

Between 250 and 500 feet the ground rises suddenly in a series of vertical cliffs. The first main scarp, which occurs along this line of section, immediately above the 300-foot contour-line, is formed by thickly-bedded limestone, free from chert, containing *Productus* 'aff. *giganteus*', *Dibunophyllum* sp., and *Cyathophyllum murchisoni*; a characteristic feature at this level, also noted in other parts of the county, is the abundance of *Euomphalus acutus.* At the top of the second scarp *Alveolites septosa* and *Lithostrotion junceum* are abundant. The ground above 500 feet, though rising in a number of minor scarps, has a gradual slope up to the summit (939 feet). Fossils are everywhere extremely scarce, though the occurrence of *Cyathophyllum regium* at certain levels suggests that the D_2 subzone has been reached. *Productus giganteus,* a large *Chonetes* cf. *compressa*, *Carcinophyllum* sp., and *Lithostrotion junceum* were also recorded. Chert is once more found in abundance near the summit.

The limestone-beds immediately below the Pendleside Shales were examined in the region around Slieve Elva, but with the exception of crinoid fragments and a small *Chonetes*, they appeared to be devoid of fossils. Dr. Wheelton Hind, however, has recorded [1] *Pterinopecten papryraceus*, *Glyphioceras diadema*, and *Lithostrotion* sp. from the topmost beds of the limestone in the neighbourhood of Lisdoonvarna. The presence of the last-named genus is somewhat remarkable, for in other parts of the county it is typically absent at this level, which is characterized by Densiphylloid Zaphrentids and *Caninia.* The evidence thus suggests, either a slight local unconformity, or merely a difference in bathymetrical conditions.[2]

[1] See Bibliographical List, § IX, p. 582.

[2] Though I have explored most of the surface of the Burren plateau, a stretch of bare rock over 100 square miles in extent, it was found impossible to furnish any connected results of zonal value: I must, therefore, of necessity omit an account of this wild and remarkable district.

VI. Correlation[1] of the Succession in County Clare with that of other Districts in the British Isles.

The *Modiola* Phase.

The lamellibranchs found in these beds cannot, in the present state of our knowledge, be definitely correlated with those occurring at the base in other districts. In this district they are not associated with a brachiopod fauna, and consequently the beds are strongly marked off from those of the succeeding zone. Their chief interest lies in the suggestion which they afford of a conformable transition from the Old Red Sandstone. (I have retained the term '*Modiola* Phase' to preserve uniformity with former papers on the Carboniferous sequence.)

The *Cleistopora* Zone.

The sandy basement-beds assigned to this zone exhibit an incomplete development of the fauna characteristic of the *Cleistopora* Zone in the South-Western Province (Bristol area and the Mendips). The correlation is based on the simultaneous occurrence of a bassiform *Productus* and *Spiriferina octoplicata*; on the presence of *Eumetria* aff. *carbonaria*, *Camarotœchia mitcheldeanensis*, and *Orthotetes crenistria* in a mutation similar to that found in K_1 of the Avon section; and on the complete absence of *Zaphrentis*, which occurs in great abundance in the overlying beds.

The absence or great rarity of *Spirifer* aff. *clathratus*, *Rhipidomella michelini*, *Productus* cf. *burlingtonensis*, and *Syringothyris* aff. *cuspidata*, from beds immediately below those containing *Zaphrentis*, enables a more marked divisional line to be drawn between this and the succeeding zone than in the South-Western Province, and suggests a relative acceleration of the coral-fauna on the brachiopod-fauna at the base of the sequence.

The extreme thinness of this zone has been mentioned above.

[1] Since the publication of Dr. Vaughan's paper on the Bristol area, much detailed work has been done on Carboniferous palæontology. I have adhered for the most part to the original names given in that paper, for the purpose of avoiding confusion in correlation. The following changes have, however, been inserted (taken from the work of Mr. R. G. Carruthers on certain Tournaisian corals, Geol. Mag. dec. 5, vol. v, 1908, pp. 25, 67, & 159):—

Zaphrentis omaliusi = *Z.* aff. *phillipsi* (pars). (Bristol paper.)
Zaphrentis konincki = *Z. cornucopiæ*. (Bristol paper.)
Caninia cornucopiæ = *Amplexi-Zaphrentis*. (Rush paper.)

The *Zaphrentis* Zone.

The correlation of these beds with the *Zaphrentis* Zone of the Bristol area is based on the following details of the faunal sequence common to the two districts.

A. The *clathratus* subzone.

1. The entrance of Zaphrentids at the base, but the absence of *Zaphrentis konincki.*
2. The maximum of *Rhipidomella michelini, Productus* cf. *burlingtonensis,* and *Spirifer* aff. *clathratus* (the subzonal index).
3. The absence or rarity of *Michelinia, Caninia,* and *Syringopora.*
4. The absence of *Schizophoria* aff. *resupinata* and *Syringothyris laminosa.*
5. The absence of *Camarotœchia mitcheldeanensis,* and *Spiriferina octoplicata,* except at the base.
6. The abundance of *Leptæna analoga* and *Syringothyris* aff. *cuspidata.*

B. The *konincki* subzone.[1]

1. The entrance of *Zaphrentis konincki* and its maximum at the summit, where it is associated with *Campophyllum cylindricum* and *Caninia cornucopiæ* (horizon γ).
2. The entrance and abundance of *Michelinia* and *Syringopora.*
3. The entrance of *Syringothyris laminosa.*
4. The development of a characteristic fish-fauna.
5. The absence of Clisiophyllids and *Lithostrotion.*

The following points of difference are to be noted:—

In County Clare *Spirifer* aff. *clathratus* is still abundant at the top of Z_2; but *Schizophoria resupinata* does not occur abundantly until the succeeding zone (compare the Mendip area).

Amplexus is either absent or extremely rare in Z_2.

The thickness of this zone is about 800 feet, and it is thus comparable with the development in the Mendip area, being more than twice as thick as in the Avon section.

The *Syringothyris* Zone.

The remarkable development of this part of the sequence in the West of Ireland renders it impossible to compare it in detail with any well-known locality in Great Britain. The unfossiliferous oolites, shales, and dolomites of the Bristol area, which form so

[1] For the reasons for adopting this form as the subzonal index, in preference to *Schizophoria resupinata,* see T. F. Sibly, Quart. Journ. Geol. Soc. vol. lxii (1906) p. 355, and A. Vaughan, *ibid.* p. 301, footnote.

marked a break in the succession, are represented in the Mendips by fossiliferous limestones exhibiting a complete transition from the Tournaisian fauna to the Viséan. In County Clare, on the other hand, although these beds afford abundant evidence of the existence of relatively shallow-water conditions and at the same time are the most fossiliferous of the whole sequence, the fauna which they contain is, on the whole, distinct from the Tournaisian below and the Viséan above, and seems to bear a marked resemblance to that of M. Édouard Dupont's Waulsortian Phase of Belgium.

The correlation of these beds with the *Syringothyris* Zone of Great Britain is, however, based on the following points, and a more detailed comparison with the Belgium sequence will be given below:—

1. These beds occur immediately above the maximum of *Zaphrentis konincki, Michelinia favosa, Caninia cornucopiæ*, and *Campophyllum cylindricum* (horizon γ).
2. They are succeeded by beds containing the earliest Clisiophyllids and *Lithostrotion*, associated with a typical S_1 fauna.
3. *Syringothyris cuspidata*, the zonal index of the Mendip area, attains its maximum development in this zone.
4. Both in County Clare and in the Mendips there is an abundance of large *Euomphali* at this horizon (*Euomphalus pentangulatus*).

The main differences in the faunal succession are, of course, due to the entirely distinct conditions under which the deposits in the two areas were la.. down; and it is hardly necessary again to emphasize the predominance of a molluscan fauna at this horizon in County Clare, as also the entire absence of corals with the exception of *Amplexus*.

This type of deposit seems to extend over the greater part of Central Ireland, occurring in Limerick, Queen's County, Kildare, etc. Dr. Vaughan informs me that there is a similar development of the *Syringothyris* Zone at St. Doolagh's (County Dublin).

Note on the Comparison of the *Syringothyris* Zone, as developed in County Clare, with the Waulsortian Phase of Belgium.

A preliminary comparison of the British Carboniferous succession with that of Belgium was given by Dr. Vaughan in his paper on the Bristol area, and he, I believe, contemplates further work on this subject. I shall, therefore, not attempt here to give more than a brief outline of the points of resemblance, both palæontological and lithological, which exist between the uppermost beds of the Lower Avonian (the *Syringothyris* Zone) as developed in the West of Ireland, and the deposits of the Waulsortian Phase of Belgium (Étage II of M. Édouard Dupont).

<table>
<tr><th></th><th>Belgian sequence.
(M. Éd. Dupont.)[1]</th><th>County Clare.</th><th></th></tr>
<tr><td rowspan="2">Étage II.</td><td>WAULSORTIAN PHASE.
'Calcaire gris à veines bleues et dolomie grise et calcaire gris souvent magnésien, dont un groupe des couches est rempli de noyaux spathiques radiés.'
(Assise IV, op. cit. p. 623.)</td><td>SYRINGOTHYRIS ZONE.
Grey, white, and black-veined and mottled limestones, often magnesian and becoming a true dolomite at the top. Certain beds are crowded with bryozoa, which give in cross-section a characteristic spotted appearance to the rock.</td><td rowspan="2">Syringothyris Zone.</td></tr>
<tr><td colspan="2">The following list comprises a few of the more important fossils which are common at this level in the two areas. (My authorities for the Belgian forms are Prof. Gosselet and L. G. de Koninck):—
Spirifer subcinctus.
Spirifer pinguis.
Syringothyris cuspidata.
Productus semireticulatus.
Spirifer attenuatus.
Dielasma kingi. Dielasma hastatum.
Athyris ingens = Athyris aff. glabristria.
Vestinautilus carinifer.
Conocardium hibernicum.
Cardiomorpha egertoni.
Euomphalus pentangulatus.</td></tr>
<tr><td>Étage I.</td><td>Tournaisian.
'Calcaire à crinoïdes, avec schistes argileux...à la base: sans schistes...à la partie moyenne; avec phtanites à la partie supérieure.'</td><td>Crinoidal limestone with the Lower Limestone Shales below, and a well-marked cherty horizon at the summit.</td><td></td></tr>
</table>

The *Seminula* Zone.

The distinction between a lower subzone (S_1), containing survivors of a Tournaisian fauna, and an upper subzone (S_2) is not well marked in County Clare; and, although the base is defined by a characteristic faunal assemblage distinct from that of the *Syringothyris* Zone, with no horizon of faunal overlap, the topmost beds of the zone merge insensibly into those of the *Dibunophyllum* Zone.

[1] Bull. Acad. Roy. Belg. ser. 2, vol. xx (1865) pp. 621 *et seqq.*

The following points are of especial interest in correlating these beds with the *Seminula* Zone in the South-Western Province of Great Britain :—

1. In County Clare, Clisiophyllids and *Lithostrotion* have not been recorded from the *Syringothyris* Zone, but appear for the first time in S_1. Since, however, *Lithostrotion martini*, which throughout is the dominant coral, is in some localities absent, or extremely rare, at the base of the subzone, this horizon is defined by the first appearance of the Clisiophyllids.
2. The survivors of a Tournaisian fauna are not numerous. They include *Campophyllum cylindricum*, which, as in the Bristol sequence, attains its second maximum in S_1, *Zaphrentis omaliusi* var. *densa*, and *Michelinia grandis.*
3. *Syringothyris cuspidata* does not extend into these beds.
4. *Daviesiella* cf. *comoides* is abundant in S_1 (compare the Mendips).
5. *Productus punctatus* is not uncommon (compare Weston-super-Mare).
6. *Productus* cf. *semireticulatus* occurs sparingly in S_1, and *Pr. cora* is abundant throughout S_2.
7. The most characteristic feature in S_2 is the horizon of *Nematophyllum* and *Carcinophyllum*, which I believe is also recognized in the North of England.
8. *Seminula* is everywhere rare, except at the summit of S_2.
9. As in the Bristol area, this zone is characterized lithologically by the development of oolitic limestone ; here, however, it sometimes attains the nature of a conglomerate, and is remarkable for its abundant gasteropod-fauna, whereas *Seminula* is absent or extremely rare in these beds. I have been unable to determine the exact level of these oolitic beds, but they probably occur at or about the base of S_2.

The simultaneous occurrence of *Syringopora reticulata* and *Michelinia grandis* at the base of S_1 suggests a correlation with the *megastoma* beds of the Rush sequence.

The *Dibunophyllum* Zone.

D_1 = subzone of *Dibunophyllum* θ.

This subzone in County Clare attains a thickness which cannot be less than 1000 feet, and is thus comparable with the sequence in the Midland area. The corals are more or less similar in the two districts, though certain forms, such as *Cyathophyllum murchisoni*, *Alveolites*, and *Carcinophyllum*, which are rare in the Midlands, are here of common occurrence. The brachiopods are more numerous in County Clare, and it is interesting to note that such forms as *Dielasma hastatum*, *Seminula ambigua*, *Productus elegans*, *Athyris planosulcata*, and *Martinia lineata* which in the Midlands characterize D_2 are here abundant in D_1 ; whereas many of the Midland D_1 forms are in County Clare more commonly associated with *Lonsdalia.*

The correlation of these beds with the D_1 subzone of the South-

Western Province of Great Britain is based on the following facts:—

1. The abundance throughout of simple *Dibunophylla.*
2. The absence of more advanced Clisiophyllids, including *Lonsdalia,* and of *Cyathophyllum regium.*
3. The maximum of *Cyathophyllum murchisoni.*
4. The gradual replacement of *Lithostrotion martini* by *L. irregulare* and *L. junceum.*
5. The presence of Clisiophyllid Lithostrotions.
6. The abundance of *Alveolites* and *Syringopora geniculata.*
7. The abundance throughout of *Productus* 'aff. *giganteus.*'
8. The occurrence of *Productus hemisphericus* and *Daviesiella* aff. *comoides.*

D_2=subzone of *Lonsdalia floriformis.*

The fauna of this subzone is very scanty, and corals are poorly represented; brachiopods, too, are nowhere abundant, and there is no evidence of the existence at this period of a 'knoll-phase,' such as occurs in the Midlands.

A correlation with the D_2 subzone of the South-Western and Midland Provinces of Great Britain is based on the following facts:—

1. The occurrence of highly specialized Clisiophyllids. *Lonsdalia duplicata,* as in the Midlands, is here abundant in the topmost beds.
2. The relative abundance of *Cyathophyllum regium.*
3. The abundance of *Lithostrotion junceum.* (Compare the Midlands.)
4. The abundance of *Productus giganteus* and *Pr.* '*corrugato-hemisphericus*'.

D_3=subzone of *Cyathaxonia rushiana.*

The topmost beds of the limestone in County Clare contain a fauna which is distinct from that of the *Lonsdalia* subzone and bears a marked resemblance to that of the *Cyathaxonia* Zone of the Midlands, the Rush sequence, and the upper D beds of Oystermouth (Gower).

Cyathaxonia, the subzonal index, has not been recorded, and such forms as *Beaumontia* and *Cladochonus* are either absent or extremely rare.

The facts on which the correlation is based are:—

1. The abundance of Densiphylloid Zaphrentids—*Zaphrentis enniskilleni* and *Z. oystermouthensis.*
2. The common occurrence of *Caninia* aff. *cornucopiæ* (*Amplexi-Zaphrentis*).
3. The absence or great rarity of Clisiophyllids, including *Lonsdalia.*
4. The absence of *Lithostrotion.*[1]
5. The abundance of scabriculate, costate, and punctate *Producti.*

[1] Dr. Wheelton Hind has recorded *Lithostrotion* from the topmost limestone-beds in the neighbourhood of Lisdoonvarna.

VII. Summary of Conclusions.

The total thickness of Carboniferous Limestone in County Clare amounts to about 3250 feet, and the zonal sequence of the contained fauna is found to be essentially similar to that of other British areas, and to admit of more or less accurate correlation.

The Lower Limestone is found to contain a Tournaisian fauna, the Upper a Viséan, the distinction between the two being well marked.

The Old Red Sandstone is succeeded in apparent conformability by a bed of sandstone containing abundant modioliform lamellibranchs.

The *Cleistopora* Zone is poorly represented by a few feet of sandy shales at the base of the sequence.

To the *Zaphrentis* Zone is assigned the whole of the so-called Lower Limestone Shales and bedded cherty limestones.

The faunal characters of the *clathratus* and *konincki* subzones are well marked, and the succession of the fauna is very similar to that of the South-Western Province of Great Britain.

Between the uppermost beds of the *Zaphrentis* Zone and the base of the Viséan occurs a considerable thickness of massive unbedded limestone, which is remarkable for its luxuriant molluscan fauna, especially large cephalopods. The peculiar nature and the faunal contents of this rock suggest the incoming of shallow-water conditions, and thus afford evidence of the extension westwards of that general elevation which is indicated by the deposits of the Bristol area, the volcanic rocks of Weston-super-Mare, and the Pendine and Rush Conglomerates.

Syringothyris cuspidata here attains the acme of its development, and the beds are assigned to the *Syringothyris* Zone. A comparison is made between this part of the sequence and the Waulsortian Phase of Belgium.

The Viséan is marked by the incoming of a perfectly distinct fauna, including the Clisiophyllids and *Lithostrotion*, and by a notable change in the nature of the rock: at least one horizon of oolitic limestone occurs in the *Seminula* Zone. This portion of the sequence is poorly fossiliferous, and the subzones are not well marked. *Productus cora* mut. S_2, however, occurs abundantly near the summit.

The *Dibunophyllum* Zone attains a thickness equal to that of the Midland development, and is composed of limestone from base to summit. The D_1 subzone is characterized by the abundance of simple *Dibunophylla*; the D_2 subzone by the occurrence of *Lonsdalia* and *Cyathophyllum regium*; and D_3 by the abundance of Densiphylloid Zaphrentids and *Caninia*, and by the apparent absence of Clisiophyllids and *Lithostrotion*.

Fossils characteristic of the lowest Pendleside Beds have not been recorded from County Clare; but it has been shown by Dr. Wheelton Hind[1] that the so-called 'Coal Measure Shales' which immediately succeed the limestone are the homotaxial equivalents of some part of that series.

[1] See Bibliographical List, § IX, p. 582.

In conclusion, I wish to offer my sincere thanks to all those who have given me their help in the preparation of this paper. To Dr. Vaughan I owe a deep debt of gratitude for his continuous encouragement and invaluable advice, and for permission to study his collection of Avonian fossils.

I have to thank Dr. Bather, for naming crinoids; Dr. Wheelton Hind, for help in regard to some of the lamellibranchs; and Mr. R. G. Carruthers, for naming several of my corals. My thanks are also due to Mr. Woods, for assistance in finding M'Coy's type-specimens in the Sedgwick Museum at Cambridge; to Prof. Grenville Cole, for permission to examine the 6-inch MS. Geological Survey maps of the county; and to Prof. Sollas and Prof. Garwood, for several helpful suggestions during the course of my work.

I am much indebted to Mr. E. R. Lloyd, for his assistance and companionship in the field during the summer of 1907; and to Mr. C. J. Bayzand, for the map (fig. 3, p. 543) showing the outcrop of the limestone.

VIII. Palæontological Notes.

(A) Brachiopods.

Dielasma.

Dielasma hastatum (Sow.).

British examples of the genus *Dielasma* are exceedingly numerous and varied, and a systematic study of the group would no doubt tend to separate forms now included under the specific name of *Dielasma hastatum* into a number of distinct species. The Belgian shells were studied in detail by L. G. de Koninck, who figured and described no less than thirty-two species.[1] Sowerby's original type-specimen, figured in his 'Mineral Conchology,' was obtained from Limerick, and without doubt came from the *Syringothyris* Zone. Identically similar forms are common in this zone in County Clare. It would be outside the limits of this paper to give a detailed account of the different forms of *Dielasma* found in this area, but a few well-marked types seem to demand reference.

1. *Dielasma* aff. *kingi* (de Kon.), Pl. XXVI, fig. 3. This shell bears a close resemblance to *Dielasma kingi*, de Kon., figured in Ann. Mus. Roy. Hist. Nat. Belg. pl. ii, figs. 36–37 & pl. iv, figs. 14–15. It agrees with this species in the relative dimensions of length to breadth, which are much less than in *D. hastatum*, and in the thick truncated anterior margin, which is only very slightly indented. The sinus in the ventral valve is shallow, though well marked, and confined to the anterior portion of the shell. The dorsal valve is flattened or feebly convex, and does not possess a sinus. The nearest approach to this form, figured by Davidson in his

[1] Ann. Mus. Roy. Hist. Nat. Belg. vol. xiv, 1887.

'Monograph of the British Fossil Brachiopods' vol. ii, is represented by fig. 7 in pl. i (*Terebratula hastata*).

2. In D_1 occurs a form with a narrow wedge-shaped anterior margin, and very convex valves without depressions, which resembles *Dielasma itaitubense*, de Kon. (*op. cit.* pl. v, figs. 4 & 5). This is probably closely related to *D. ficus* (M'Coy).

3. The most abundant form in D, however, is similar to that figured by Davidson (*op. cit.* pl. i, fig. 12) as *Terebratula virgoides*, M'Coy.

It would appear then, from a brief study of the history of the genus, that *D. virgoides* (M'Coy) and *D. ficus* (M'Coy), which Davidson includes as varieties of *D. hastatum* (Sow.), must rank as distinct species.

Athyris.

Athyris glabristria (Phill.). (Pl. XXVI, fig. 2.)

The typical form of this shell, as described and figured by Phillips in the 'Geology of Yorkshire' pt. ii, p. 220 & pl. x, fig. 19, and by Davidson, under the name of *Athyris royssii*, in his 'British Fossil Brachiopoda' (vol. ii, pl. xviii, figs. 1–11), is enormously abundant in the *Syringothyris* Zone of County Clare, though somewhat scarce in the beds below. This species exhibits a remarkable variation in growth, and hardly any two specimens obtained from this level have the same relative dimensions.

The ratio of length to breadth in three specimens taken at random was found to be 4 : 7, 4 : 10, and 4 : 13.

The young shell is depressed, with a slight median fold. In some cases, further growth is chiefly directed towards increasing the depth of the shell, resulting in a deep form with rounded fold; in others, there is little increase in depth: the shell remains flattened, and may become extremely transverse; the fold in this type is often very prominent, with steep sides. There can be little doubt that this form is identical with *Athyris ingens* of L. G. de Koninck, which characterizes the Waulsortian Phase of Belgium (*op. cit.* pl. xx, figs. 1–10). In comparing this species with other Athyrids the author lays stress on the absence of ornamentation:—

'. . . . l'auteur [Davidson] a dû admettre que les spécimens représentés avaient perdu leurs ornements pendant la fossilisation, ce qui ne paraît pas d'accord avec leur parfait état de conservation.' (Pp. 83–84.)

The preservation of fringe-like expansions on the shell is dependent largely on the mode of fossilization, and their apparent absence from the Belgian type of *A. ingens* cannot be taken as proof of their non-existence. Many specimens that I have collected from County Clare present, at first sight, a perfectly smooth surface which shows little trace of ornamentation; but, on grinding and polishing the matrix in which they are embedded, the presence of fringes can always be determined.

ATHYRIS HIBERNICA, nom. nov. (Pl. XXVI, fig. 5.)

Athyris phalæna (M'Coy); *Athyris squamigera*, de Kon. & Davidson.

This species, though incorrectly referred to Phillips's *Spirifer phalæna*, was first described by M'Coy in 1844.[1] In 1857 Davidson figured and described M'Coy's actual specimen[2] under the name of *Athyris squamigera*, a species first described by L. G. de Koninck in 1851,[3] and stated that he had communicated his specimens to the latter, who with some hesitation referred them to this species.

The strongly-marked ornamentation shown in de Koninck's figures, together with the shape and relative dimensions of the shell, would appear, however, to distinguish it at once from M'Coy's type, which is transversely elongated and has very feeble concentric ornamentation.

In 1887[4] L. G. de Koninck again described *A. squamigera*, and stated that he had grave doubts whether M'Coy's form figured by Davidson belongs to the same species; and a comparison of the two figures can only lend strong support to this view. M'Coy's type is common in the *Syringothyris* Zone of Clare, and, as the original name of *Athyris phalæna* by the law of priority belongs to Phillips's Devonian form, I have substituted the new specific name *hibernica*, this shell at present being only known from Ireland.

Description:—

'Transversely oval, much broader than long; valves convex, sometimes gibbous; beak in the ventral valve moderately produced, incurved and truncated at its extremity by a small circular aperture. In the dorsal valve there exists a prominent broad mesial fold, and in the ventral a corresponding sinus of variable depth, both commencing at a short distance from the extremity of the beaks. Surface with small imbricating striæ.'

The concentric striæ are the more strongly marked, and probably indicate the original presence of fringed ornamentation as in *Athyris glabristria*; in fact, this shell may ultimately prove to be an extremely transverse variant of that species.

ATHYRIS LAMELLOSA (L'Éveillé). (Pl. XXVI, fig. 4.)

A form similar to that figured by Dr. Sibly[5] occurs commonly at the base of the *Zaphrentis* Zone in County Clare. The shell-expansions are, however, seldom preserved, although the two series of concentric ridges resulting from their fracture are well shown in the figure of a young specimen.

[1] 'Syn. Carb. Limest. Fossils of Ireland' p. 140.

[2] 'Monogr. Brit. Foss. Brach.' (Palæont. Soc.) vol. ii, p. 83 & pl. xviii, fig. 13.

[3] 'Description des Animaux fossiles du Terrain Carbonifère de Belgique' (Suppl.) p. 667 & pl. lvi, fig. 9.

[4] Ann. Mus. Roy. Hist. Nat. Belg. vol. xiv, pp. 82–83.

[5] Quart. Journ. Geol. Soc. vol. lxii (1906) pl. xxxii, figs. 1 *a* & 1 *b*.

Spirifer.

SPIRIFER ATTENUATUS, Sow. (Pl. XXVI, fig. 7.)

The opinion that this shell was only a variety of *Spirifer striatus* was held by de Verneuil, M'Coy, Davidson, and for a long time by de Koninck. The last-mentioned author, however, has since published a description of *Spirifer attenuatus* as a separate species, and has brought forward abundant evidence to justify the distinction. This shell, which is characteristic of the Waulsortian Phase of Belgium, occurs also in great numbers in the *Syringothyris* Zone of County Clare. The specimen that I have figured was selected to show the nature of the ribbing, but the posterior lateral extremities, which are always angular, are unfortunately broken. De Koninck's figures are somewhat poor, and the best example is to be found on pl. ii, fig. 13 of Davidson's 'Monograph of British Fossil Brachiopoda' vol. ii (1857–63).

The following is L. G. de Koninck's description of this species (Ann. Mus. Roy. Hist. Nat. Belg. vol. xiv, 1887, p. 115):—

'Shell transverse, much broader than long, of a subsemicircular form with angular lateral extremities; valves of nearly equal depth. The median fold of the dorsal valve is fairly broad at its anterior border, but is very little elevated and evenly rounded. The sinus of the ventral valve is fairly deep, and bounded on each side by a radial rib, a little more strongly marked than the adjacent ones. . . . . The surface of each valve is covered by narrow ribs separated by grooves of equal width and fairly deep. The ribs, which are the same on the fold and sinus as on the rest of the shell, bifurcate several times, and thus preserve almost their initial width throughout their length. The first bifurcation takes place at a short distance from the beaks, and the ribs sometimes collect into bundles which divide the surface into several small, more or less isolated lobes. . . . . The ribs are smooth for the greater part of their length, and are only interrupted by transverse lines of growth, often at unequal distances, near the margin of the shell.'

The figured specimen shows three well-marked bundles on the dorsal fold, which have their origin in three primary ribs.

This species differs from *Spirifer striatus*, chiefly by its smaller size, and by the fineness and regularity of its ribs and the characteristic grouping into bundles.

SPIRIFER aff. CLATHRATUS, M'Coy & Vaughan. (Pl. XXVI, fig. 6.)

As interpreted by Dr. A. Vaughan, Proc. Bristol Nat. Soc. n. s. vol. x (1902–1903) pp. 125–27, and Quart. Journ. Geol. Soc. vol. lxi (1905) p. 300 & pl. xxvi, fig. 5.

This species is abundant throughout the *Zaphrentis* Zone in County Clare; it continues into the *Syringothyris* Zone, from which the figured specimen was derived.

SPIRIFER KONINCKI, sp. nov. (Pl. XXVI, figs. 1 *a* & 1 *b*.)

Description.—The young shell is nearly circular in outline, but becomes transversely oval with increased growth. Area rather broad, concave, with subparallel sides; cardinal angles rounded. Beaks prominent, incurved over the large triangular delthyrium.

The ventral valve is more convex than the dorsal. Ribs numerous, rounded or slightly flattened.

In the dorsal valve a median fold, bounded on each side by a distinct groove, has its origin near the extremity of the beak; but it does not become prominent until it approaches the anterior margin of the shell, where it is considerably elevated, with steep sides, and bears usually about twelve ribs. The sides of the dorsal valve in an adult shell are somewhat flattened, and each bears about fifteen prominent ribs and numerous smaller ones towards the cardinal angles. A few ribs on each side of the median fold increase by bifurcation.

The ventral valve possesses a prominent though shallow sinus. In the young shell this is simple; but, as growth proceeds, it tends to be divided by a small median fold, formed by the fusion of four or five ribs.

In a well-preserved specimen the ribs are seen to be covered by fine longitudinal striæ, crossed by obscure lines of growth which give them a reticulated appearance.

Discussion.—This shell, in general form, in the nature of its ribbing, and in the finely reticulate surface, bears a close resemblance to the Belgian species figured and described by L. G. de Koninck as *Spirifer cinctus*, de Keys.[1] The fold, however, is stronger than in the Belgian shell, and the double nature of the sinus seems to be a distinct feature, although there is perhaps a suggestion of this in fig. 7 (*op. cit.*). The ribs, too, appear to be less numerous and not so flattened.

De Koninck's interpretation of *Spirifer cinctus* seems to be open to adverse criticism, for his figures and description bear little resemblance to those of A. von Keyserling, the founder of the species; see the latter's 'Wissensch. Beobacht. auf einer Reise in das Petschoraland im Jahre 1843' St. Petersburg 1846, p. 229 & pl. viii, fig. 2. The original type of this author appears to be readily distinguishable from all other Carboniferous Spirifers by the absence of a median fold and sinus, and by the possession of a uniplanar valvular intersection (*op. cit.* pp. 229–30):—'Der entschiedne Mangel eines Sinus unterscheidet ihn von allen Arten auf das ausgezeichnetste. . . . In Folge dessen wird die Stirncommissur nicht so wie bei anderen Arten zur Ventralschale herabgedrängt, sondern liegt fast in derselben Ebene ringsum.'

It is not easy to understand how de Koninck confounded with this species a form having a strong fold and sinus[2] (see de Kon. *op. cit.* p. 108: 'La valve ventrale . . . est déprimée dans sa partie médiane par un large sinus correspondant au lobe de la valve opposée').

A form, somewhat similar to the Irish species and probably representing a parallel stock, occurs in the Keokuk Limestone of America, which appears to correspond to our *Syringothyris* Zone. This species (*Spirifer logani*, Hall) is, however, rather more transverse, and bears more numerous ribs.[3] Of British examples

[1] Bull. Musée Roy. Hist. Nat. Belg. vol. ii (1883) pl. xv, figs. 3–5; and Annales, *ibid.* vol. xiv (1887) p. 108, pl. xxiv, figs. 6–7 & pl. xxvi, figs. 1–2.

[2] De Koninck records *Spirifer cinctus* from Ballydoole (County Limerick).

[3] 'Natural History of New York: Part VI—Palæontology' vol. viii, pt. ii (1894) pl. xxxii, fig. 7.

which are comparable with this species, mention must be made of the mutation of *Spirifer clathratus* figured by Dr. Vaughan.[1] This author considers that *Sp. konincki* is a late mutation of one of the *clathratus* group.

The form figured by Davidson on pl. iv, fig. 14, of his 'British Fossil Brachiopoda' as *Spirifer mosquensis* from Little Island (Ireland) occurs at an horizon far below that of the Russian shell; and, since the strong dental plates, diagnostic of that species and its allies which are grouped under the generic name *Choristites*, have never been determined in his specimens, it appears likely that they are related to the species now described, which (though it does not possess large dental plates) has somewhat the outward appearance of a *Choristites*.

Spirifer subcinctus, de Kon.

Specimens which occur commonly in the *Syringothyris* Zone agree closely with the form described and figured by L. G. de Koninck from the Waulsortian of Belgium.[2]

(B) Corals.

Michelinia.

Michelinia grandis, M'Coy.

'British Palæozoic Fossils' 1855, p. 81 & pl. iii C, figs. 1–1 *a*; and Ann. & Mag. Nat. Hist. ser. 2, vol. iii (1849) p. 123.

I have examined M'Coy's type-specimen, preserved in the Sedgwick Museum at Cambridge, and have no hesitation in assigning the form common at the base of S_1 in County Clare to this species.

Zaphrentis.

Zaphrentis omaliusi, M.-Edw. & H. (var. densa, Carruthers). (Pl. XXVII, fig. 9.)

As interpreted by Mr. R. G. Carruthers, Geol. Mag. dec. 5, vol. v (1908) p. 25 & pl. iv, fig. 7.

A densiphylloid *Zaphrentis*, which Mr. Carruthers refers to the above species and variety, occurs in some abundance in Z_1 of County Clare. Nearly every specimen collected was found to be silicified, and the structure thereby almost completely obscured; the figured specimen, however, shows the radial disposition of the septa and the fusion of their inner ends.

Zaphrentis konincki, M.-Edw. & H.

As interpreted by Mr. R. G. Carruthers, *op. cit.* p. 67 & pl. v, figs. 1–4.

This species occurs in great abundance throughout Z_2, reaching its maximum at horizon γ. Forma α of Carruthers is the type usually met with.

[1] Proc. Bristol Nat. Soc. n. s. vol. x (1902–1903) pl. ii, fig. 3.

[2] Ann. Mus. Roy. Hist. Nat. Belg. vol. xiv (1887) pl. xxiv, figs. 4 & 5.

Zaphrentis vaughani, sp. nov. (Pl. XXVII, fig. 11.)

Description.—Form conical or slightly cornute; epitheca exhibiting longitudinal striations and faint annular lines of growth.

Horizontal section.—The cardinal fossula, which is situated on the concave side of the corallum, is not well marked in the lower part of the coral, but in sections taken higher up is well defined and extends to the centre, the two septa which bound it being almost parallel. Just below the floor of the calyx the inner end expands rapidly. A counter-fossula is not developed. The septal arrangement is almost radial, though a slight curvature towards the fossula is sometimes noticeable. The major septa are strong, and their inner ends become fused together into a compact mass, giving the coral a densiphylloid appearance.

The cardinal septum at first completely divides the fossula, but is seen to become rapidly shorter as the sections approach the calyx-floor. The counter-septum is readily distinguished by the fact that the minor septa on each side of it are strongly developed and reach the central fused mass. These, at first sight, simulate major septa, but their true nature is easily recognizable on closer examination of the wall. The remaining minor septa, though rudimentary, are conspicuous even in the early stages of growth; towards the upper part of the corallum they project inwards a short distance from the wall.

The tabular intersections, which are rather numerous, are evenly spaced, and preserve a regular concentric arrangement.

Discussion.—This coral occurs rarely in Z_1 of County Clare, but has not been previously recorded from Great Britain; Mr. Carruthers informs me that he has a single specimen from Tournai in Belgium.

In the position of the fossula on the concave side of the corallum, the curvature of the major septa convex to the fossula, the rapid dwindling of the cardinal septum on approaching the calyx-floor, and the absence of a counter-fossula, it bears some resemblance to *Zaphrentis delanouei*, M.-Edw. & H., but is readily distinguished from that species by the fusion of the major septa, the greater number of tabular intersections, and the abnormal development of the minors on either side of the counter-septum, although the last feature is sometimes noticeable to a less extent in *Z. delanouei*.

Zaphrentis sp. (Pl. XXVII, fig. 4.)

This form is represented by a single specimen from the top of S_2. Its relations are necessarily somewhat obscure.

In its longitudinally striated epitheca and the presence of the fossula on the concave side of the corallum, it is apparently related to *Zaphrentis enniskilleni*. The fossula in the lower part of the corallum has, however, almost parallel sides, and is completely bisected by the cardinal septum. In higher sections, this septum dwindles rapidly in length, and the fossula expands widely at its inner end, having a thick stereoplasmic lining as in *Zaphrentis konincki*.

Densiphyllum.

Densiphyllum sp. (Pl. XXVII, fig. 7.)

This form, which occurs in the topmost beds of the limestone in County Clare, seems in its type of septation to bear some relation to *Cyathaxonia costata*, M'Coy, but lacks the central axis of that genus.

Campophyllum.

This genus was revised in detail by Thomson in 1893,[1] who includes in it those corals which are intermediate in structure between *Calophyllum* on the one hand and *Cyathophyllum* on the other.

Mr. R. G. Carruthers has recently shown [2] that the genotype of Michelin's genus *Caninia* is *Caninia cornucopiæ*, and the results of his investigations seem to indicate that the reasons given by Thomson for the inclusion of the forms commonly known as *Caninia cylindrica* and *C. gigantea*, which are regarded by that author as distinct species, in the genus *Campophyllum*, at least merit further consideration. Horizontal sections, however, cut near the base of *Campophyllum cylindricum*, show a striking resemblance to certain stages of growth in *Caninia cornucopiæ*, and it thus appears doubtful whether the two species should be assigned to different genera. (In County Clare, the first maximum of *C. cylindricum* occurs at the same level, Horizon γ, as that of *C. cornucopiæ.*)

Campophyllum cylindricum (Scouler). (Pl. XXVII, fig. 8.)

The mutation of this species which is common at Horizon γ is characterized by a broad vesicular outer zone, completely radiated by the two series of septa; in this respect it resembles the form characteristic of S_1 in the South-Western Province of Great Britain. It possesses, however, more numerous and thinner septa, its structure being somewhat Cyathophylloid in appearance, though the septal fossula and associated thickened septa are strongly marked.

A characteristic mutation, distinguished by the abnormal development of the minor septa, is also abundant at the base of S_1. These septa project some distance from the strong inner wall into the median area, where, together with the major septa, they become greatly thickened. Their inner ends have a rounded or blunt appearance, totally distinct from the tapering points of the major septa. The vesicular outer zone is similar to that of the form mentioned above, being radiated by the two series of thin septa, with several rows of interseptal vesicles.

[1] Proc. Roy. Irish Acad. ser. 3, vol. ii, pp. 667–758 & pls. xv–xxi.

[2] Geol. Mag. dec. 5, vol. v (1908) p. 158.

CAMPOPHYLLUM sp. (Pl. XXVII, fig. 10.)

Description.—External characters: form cylindrical and curved; epitheca strong, with longitudinal costæ.

Horizontal section.—Outer wall strong. A peripheral vesicular zone is almost entirely absent.

Major septa about 35 in number, short and never extending far towards the centre. Minor septa rudimentary. The median area is occupied solely by the tabulæ, which are remote and extend to the wall. There are no interseptal dissepiments, though intersections of downwardly curved tabulæ are seen uniting the septa. A pronounced septal fossula is visible.

Discussion.—The characters of this species seem to warrant its inclusion in the genus *Calophyllum* of Dana, which constitutes a group of corals distinguished, on the one hand from *Amplexus* chiefly by the presence of a series of minor septa, and on the other from *Campophyllum* by the absence of a vesicular outer zone. It is well known, however, that in many instances the latter is a senile character, merely denoting a comparatively late stage in the life-history of a coral; and it must, therefore, be admitted that its presence or absence is a matter of little importance in classification, and can hardly furnish sufficient grounds for the distinction of the two genera.

This species has a very feebly developed vesicular zone, and it thus seems to furnish a connecting link between *Calophyllum danai*, Thomson[1] and *Campophyllum caninoides*, Sibly.[2]

Caninia.

CANINIA CORNUCOPIÆ, Mich. (Pl. XXVII, fig. 14.)

As interpreted by Mr. R. G. Carruthers, Geol. Mag. dec. 5, vol. v (1908) p. 160 & pl. vi.

This species, which frequently presents the peculiar contorted form figured by Carruthers (*op. cit.* diagram E), is abundant throughout Z_2, attaining its maximum at Horizon γ. It also occurs sparingly near the base of S_1, but has not been recorded from the massive limestones of the *Syringothyris* Zone.

CANINIA aff. CORNUCOPIÆ, Mich. (Pl. XXVII, fig. 12.)

A form closely related to the above occurs in some abundance in the topmost beds of the limestone (D_{2-3}) in County Clare. Its chief distinguishing features are its cylindrical habit, inconspicuous septal fossula, and greater number of tabular intersections.

A similar mutation has been recorded by Dr. Vaughan from D_{2-3} of the South-Western Province, and by Dr. Sibly from D_3 of the Midlands.

[1] Proc. Roy. Irish Acad. ser. 3, vol. ii (1893) p. 687 & pl. xv, fig, 1.
[2] Quart. Journ. Geol. Soc. vol. lxii (1906) p. 368 & pl. xxxi, fig. 2 *b*.

Diphyphyllum.

Diphyphyllum aff. subibicinum (M'Coy). (Pl. XXVII, fig. 13.)

A form somewhat similar to that described by Dr. Vaughan[1] occurs at the base of D_2 in County Clare, associated with *Campophyllum* aff. *marginatum*, Thomson.

Lithostrotion.

Nematophyllum (Lithostrotion) minus, M'Coy. (Pl. XXVII, figs. 1, 2*a*, & 2*b*.) = L. strict

M'Coy, Ann. & Mag. Nat. Hist. ser. 2, vol. iii (1849) p. 17; and 'Brit. Palæozoic Fossils' 1855, p. 99 & pl. iii B, fig. 3.

A form which occurs in great abundance, and constitutes a definite horizon near the summit of S_2 in County Clare, bears a close resemblance to M'Coy's species. The type, figured in his 'Palæozoic Fossils,' which is now in the Sedgwick Museum at Cambridge, is but a poorly preserved specimen, and a description of this species from further material seems desirable.

The corallites are slightly larger than in the Clare form, but a small fragment, polished to show a vertical section, appears to have an identical structure.

The following is an emended description of this species:— Corallites prismatic, with rarely more than six sides: average diameter = about 3 lines; epitheca, when visible, exhibiting longitudinal striations. M'Coy's distinction between separable and non-separable corallites does not appear justifiable, as in many cases this is merely a matter of fossilization; specimens from the same bed differ widely in this respect, though identical in a thin section.

Vertical section.—The centre of the corallite is occupied by a thin rod-like columella, measuring about half a line in width; inner area composed of slightly curved vesicular plates, with their convex sides directed outwards and upwards; and it takes as a rule about three plates to reach from the axis to the external boundary of the area.

The outer area is of approximately the same width as the inner: it consists of four or five rows of vesicular plates, of smaller size and more regular arrangement than those of the inner area, and having their convex sides directed upwards and inwards.

Horizontal section.—Boundary between individual corallites well marked. Columella usually ill-defined, compressed laterally.

The septa average 42 in number, and the major and minor series are of equal thickness. The former reach the columella, but the latter only project a short distance beyond the inner wall. The medial area comprises about three rows of obscure vesicles, bounded by a more or less distinct inner wall. The external area has five or more rows of vesicles, with, as a rule, a regular concentric arrangement.

[1] Quart. Journ. Geol. Soc. vol. lxiv (1908) p. 461 & pl. xlix, fig. 7.

CLISIOPHYLLID LITHOSTROTION. (Pl. XXVII, fig. 3.)

This form, which is essentially similar to that figured by Dr. Vaughan[1] from D_1 of the Bristol District, occurs in some abundance near the base of D_1 in County Clare.

Dibunophyllum.

DIBUNOPHYLLUM aff. ψ, Vaughan. (Pl. XXVII, fig. 6.)

In a horizontal section this form appears to be closely related to *Dibunophyllum* ψ.[2] It agrees with the Bristol form in the thickening and extension of the mesial plate, and in the approximate number of vertical lamellæ. The central area is, however, less strongly bounded, and its cuspidate nature is not well marked, although the septal fossula is conspicuous.

The minor septa are much more strongly developed in the Irish form, even more so than in *D. matlockense*, Sibly,[3] and extend to the inner wall. The latter feature is not so well defined as in the typical *Dibunophyllum* ψ.

Carcinophyllum.

CARCINOPHYLLUM sp. (Pl. XXVII, fig. 5.)

Form conical, epitheca with faint longitudinal striations.

Horizontal section.—The central area is nearly circular, and has a sharply defined boundary. There is usually some indication of an irregular, thickened, mesial plate from which project a number of vertical lamellæ, which, as they approach the outer margin of the area, assume a spiral arrangement and often produce an open vesicular structure.

The major septa are 35 to 37 in number, and the majority of them reach the central area. The minor septa project inwards a short distance from the inner wall.

A septal break is marked by a considerable elongation of one of the minor septa. The inner wall is very conspicuous, and forms a dense ring due to the approximation and thickening of the outer ends of the two series of septa. A narrow peripheral vesicular ring is sometimes seen; but, as rejuvenescence is common, it is rarely developed to any great extent.

Discussion.—This form, which is abundant at the top of S_2 in County Clare, is closely related to *Carcinophyllum mendipense* from S_1 of the Mendip area,[4] agreeing with that species in the character of the inner wall, the marked septal break, and the compressed peripheral vesicular area, but differing in the nature of the central area which, in the Irish form, is spiral in structure as opposed to radial. It is distinguished from *Carcinophyllum curkeenense*, Vaughan,[5] by

[1] Quart. Journ. Geol. Soc. vol. lxi (1905) pl. xxiii, fig. 5.

[2] A. Vaughan, *ibid.* pl. xxiv, fig. 2 *a*. [3] *Ibid.* vol. lxiv (1908) pl. i, fig. 2.

[4] See T. F. Sibly, Quart. Journ. Geol. Soc. vol. lxii (1906) p. 369 & pl. xxxi, fig. 4.

[5] *Ibid.* vol. lxiv (1908) p. 464 & pl. xlix, fig. 5.

the projection of the minor septa from the inner wall, and from *Carcinophyllum* θ, Vaughan,[1] by the absence of a coarsely vesicular peripheral area, by the more strongly marked inner wall, and by the nature of the central area. The character of the inner wall readily distinguishes it from *Carcinophyllum kirsopianum*, Thomson.[2]

It has not been deemed advisable to assign a new specific name to this form, since it is distinguished from others chiefly by the character of its central area, which is of little value as a diagnostic feature, varying, as it does, in different sections cut from the same specimen.

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[2] Proc. Phil. Soc. Glasgow, vol. xiv (1882–83) p. 456 & pl. xii, fig. 9 *a*.

Fig. 1a.

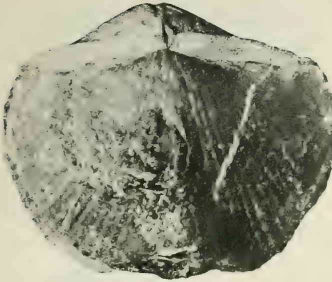


Fig 2.

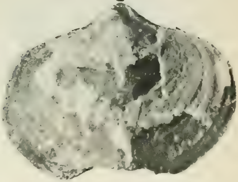
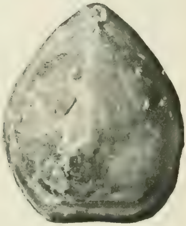


Fig. 3.



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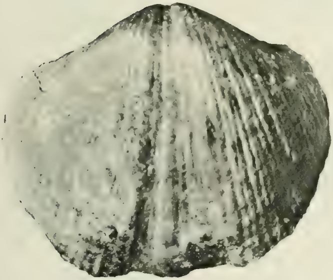

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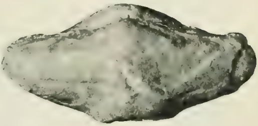

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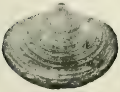
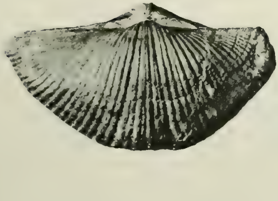


Fig. 7.

Fig. 6.



J. A. Douglas, Photogr. *Bemrose, Collo., Derby.*

AVONIAN BRACHIOPODS FROM COUNTY CLARE.

Fig. 1.

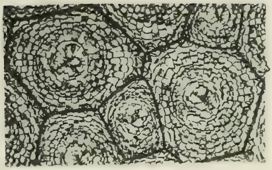


Fig. 2b.

Fig. 2a.

Fig. 3.

Fig. 4.

Fig. 5.

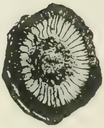


Fig. 6.

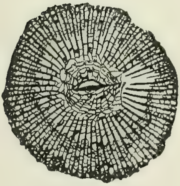
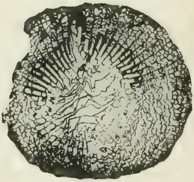


Fig. 7.

Fig. 8.



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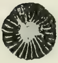


Fig. 10.

Fig. 11.

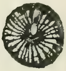
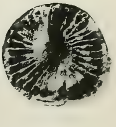


Fig. 12.

Fig. 13.

Fig. 14.



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Avonian Corals from County Clare.

EXPLANATION OF PLATES XXVI & XXVII.

[All the figures are of the natural size, unless otherwise stated.]

Plate XXVI.

Avonian Brachiopods from County Clare.

Fig. 1 *a*. *Spirifer konincki*, sp. nov., dorsal view. *Syringothyris* Zone, Cratloe.
1 *b*. The same specimen, ventral view. (See p. 574.)
2. *Athyris glabristria* (Phill.). *Syringothyris* Zone, Tulla. (See p. 572.)
3. *Dielasma* aff. *kingi*, de Kon. *Syringothyris* Zone, Crusheen. (See p. 571.)
4. *Athyris lamellosa* (L'Éveillé). *Clathratus* subzone, Gourna River. (See p. 573.)
5. *Athyris hibernica*, nom. nov. *Syringothyris* Zone, Cratloe. (See p. 573.)
6. *Spirifer* aff. *clathratus*, M'Coy & Vaughan. *Syringothyris* Zone, Cratloe. (See p. 574.)
7. *Spirifer attenuatus*, J. de C. Sow. *Syringothyris* Zone, Cratloe. (See p. 574).

Plate XXVII.

Avonian Corals from County Clare.

Fig. 1. *Nematophyllum (Lithostrotion) minus*, M'Coy. Much enlarged. S_2, Ballyvaghan. (See p. 580.)
2 *a*. The same. Natural size.
2 *b*. Vertical section of one corallite.
3. Clisiophyllid *Lithostrotion*, Vaughan. D_1, Ballyvaghan. (See p. 581.)
4. *Zaphrentis* sp. S_2, Ballyvaghan. (See p. 577.)
5. *Carcinophyllum* sp. S_2, Ballyvaghan. (See p. 581.)
6. *Dibunophyllum* aff. ψ. D_2, Glencolumbkille. (See p. 581.)
7. *Densiphyllum* sp. D_3, Corrofin. (See p. 578.)
8. *Campophyllum cylindricum* (Scouler). Horizon γ, Sixmilebridge. (See p. 578.)
9. *Zaphrentis omaliusi*, var. *densa*, Carr. Z_1, Gourna River. (See p. 576.)
10. *Campophyllum* sp. S_1, Crusheen. (See p. 579.)
11. *Zaphrentis vaughani*, sp. nov. Z_1, Gourna River. (See p. 577.)
12. *Caninia* aff. *cornucopiæ*, Mich. D_3, Bushy Park House. (See p. 579.)
13. *Diphyphyllum* aff. *subibicinum* (M'Coy). D_2, Glenquin. (See p. 580.)
14. *Caninia cornucopiæ*, Mich. Calyx. Horizon γ, Sixmilebridge. (See p. 579.)

Discussion.

The President (Prof. Sollas) congratulated the Author on his earnest and long-continued labours having culminated in so successful a conclusion. It was extremely gratifying to find that the facts in County Clare were in general harmony with those observed on the banks of the Avon; confidence in the zonal method and in the particular system of zones proposed for the Carboniferous Limestone was thereby strengthened. The discovery of the Waulsortian fauna in its proper place, between the Viséan and the Tournaisian, was a very fortunate circumstance; it added to the completeness of the British series in a locality as far west as the zoning of the Carboniferous could be carried in the Old World. The next step must be to

trace the zones into the East, and the discovery of leading fossils in Tian-Shan was of happy augury. The alliance of petrological and palæontological characters, so strikingly illustrated by the correspondence between the boundary-line adopted by the Irish surveyors in the field and that based on zonal palæontology, was continually gaining in importance, and might still have some unexpected application in store.

Dr. T. F. Sibly expressed his satisfaction in learning that the faunal succession of the South-Western Province was so closely paralleled in the distant region of the West of Ireland. The sequence described by the Author was one of exceptional interest. Each zone, and almost every subzone, of the typical Avonian succession appeared to be clearly defined; while the additional development of a *Cyathaxonia* subzone constituted an extension of the typical sequence, and furnished an interesting point of agreement with the succession in the Midland Province, where that subzone formed so conspicuous a feature. The great thickness of the *Dibunophyllum* Zone was another characteristic in common with the Midland development. Special points to which the speaker drew attention were, the large development of chert in the Upper *Zaphrentis* Zone (paralleled in the Mendip area), and in the Burren Limestone (paralleled in part by the great cherty series of D_2 in the Midlands); also the occurrence of *Lonsdalia duplicata*, an uncommon and very distinctive fossil, at the precise horizon at which the same species occurred in Derbyshire, namely, the top of D_2. In conclusion, he wished to congratulate the Author upon his successful investigation of a very important area.

Mr. Cosmo Johns said that he was pleased to learn that a normal Carboniferous development, so far west as County Clare, had been carefully investigated. He would have liked a more detailed account of the fauna which marked the base of the Viséan: in many parts of Britain it formed a distinct and very important horizon. It would also be interesting to learn the nature of the evidence on which the Author relied when drawing a line between the several zones. A very desirable method of investigation would be to map the more important faunal lines for comparison with a map indicating the lithological divisions. He thought that caution should be exercised in referring to the divisions that had been made in the Belgian sequence. The tangled sections of that country would best be straightened out by reference to the many clear and uninterrupted exposures in Britain.

Dr. Ivor Thomas deprecated the use of the names 'Viséan' and 'Tournaisian' at the present stage of Carboniferous Limestone research, especially as the Belgian sequence had not yet been zoned on the lines suggested by Dr. Vaughan. Moreover, the typical Viséan and Tournaisian of Belgium appeared to be only locally developed. The Viséan of Visé passed downwards into a mass of practically unfossiliferous dolomitic rocks—the so-called 'Devonian' of certain Belgian geologists; while the Tournaisian of the Namur

district was not followed by typical Viséan. Since the district under consideration showed such an agreement with the Bristol sequence, it would seem preferable to use Dr. Vaughan's names—Clevedonian and Kidwellian. The Author was to be congratulated upon the clearness with which the paper was set forth.

Mr. W. P. D. Stebbing drew attention to the, to him, peculiar physical features shown by some of the views of the bare fissured limestone of the northern part of the area dealt with, and said that it reminded him of the eaten-out surface of the top of one of the spurs of the Carrara range above Massa-Carrara. The mountain-top, from which a black-veined marble was quarried, to which he referred, was similarly cut up; but a certain amount of coarse vegetation grew on the surface, and the quarrying showed that red earth partly filled the fissures.

Mr. R. H. Tiddeman begged to remind the previous speaker that bare and arid tracts of Carboniferous Limestone were by no means so rare as he had seemed to imply. They were quite common in the North-West of England on and about the Pennine chain, as, for instance, around Ingleborough. The Author's description of the limestone reminded him generally of the succession in the Clitheroe district near Pendle.

Prof. Garwood referred to the name *Syringothyris-cuspidata* Zone, and asked the Author whether this species occurred also in beds of D_2 age in his area, as was the case in Derbyshire. Martin's type-specimen (he understood) came from beds of D_2 age at Castleton, not from C_2. He was interested to hear that the well-marked break which occurred above C_2 in the Northern Pennines was also found in the Author's district; he thought that a widespread period of submergence would be found everywhere at the beginning of S_2. He considered that the coincidence between the lithological character and the faunal zones to which previous speakers had alluded was only what might be expected: for instance, *Zaphrentis enniskilleni*, which was limited to the shaly beds at the top of C_2 in Westmorland, survived into higher beds in the Isle of Man, where the argillaceous type of deposit continued longer, and was again characteristic of D_2 under similar conditions elsewhere. He congratulated the Society on receiving another important contribution on this interesting subject.

The Author regretted that lack of time prevented him from answering many of the questions in detail. In reply to Prof. Garwood, he said that very large specimens of *Syringothyris cuspidata* were common in the *Syringothyris* Zone, but the genus seemed to be entirely absent from the Viséan. Zaphrentids closely allied to *Zaphrentis enniskilleni* were found as low down as the *Seminula* Zone.

Replying to the President, he thought that the enormous abundance of large-sized individuals in the *Syringothyris* Zone among all classes of the mollusca and of the brachiopoda, as well as the great number of species represented, was not at all suggestive of

deep-water conditions; moreover, a few miles to the south, the Limerick volcanic rocks were found at this level, affording further proof of elevation. With regard to the origin of the chert, it was of interest to note that in the topmost beds it was found to occur in well-defined tabular bands, but elsewhere in the succession as nodules scattered throughout the limestone.

In reply to Dr. Thomas, the Author said that he had visited Belgium, and had been much impressed with the similarity between the fauna of the Tournaisian and Viséan limestones and that of the British Carboniferous Limestone. In conclusion, he thanked all those Fellows who had taken part in the discussion, and at the same time took the opportunity of expressing his thanks to the Council of the Society for their award to him of the Daniel Pidgeon Fund.

31. *The* Howgill Fells *and their* Topography.

By John Edward Marr, Sc.D., F.R.S., F.G.S., and William George Fearnsides, M.A., F.G.S. (Read June 16th, 1909.)

[Plates XXVIII–XXXI.]

The Howgill Fells form a well-defined geographical unit. They occur as an upland tract of roughly triangular form, the angles being blunted. The northern side of the triangle is defined by the valley in which the village of Ravenstonedale lies. It extends for 8 miles measured in a straight line, in a direction a little north of west, from a point 2 miles south-east of that village to the village of Tebay. This valley was originally watered by the streams of the Lune drainage, although (owing to subsequent diversion) the waters at its eastern end now find their way into the Eden.

At Tebay the main waters of the Lune flow southwards, and this part of the course of the Lune forms the western side of the triangle for a distance of 8 miles to a point a little west of the town of Sedbergh. The trend of this side is about 5° east of south.

The third and longest side is curved, and measured along the straight is about 9 miles long. At the north-eastern end it is defined by the Dent Fault and its parallel fractures as far as Rawthey Bridge, after which it follows the line of the Rawthey to the southern end of the second side immediately west of Sedbergh.

Along these lines a continuous depression separates the Howgill Fells from the adjoining heights on the west, north, and south-east. The bottom of this depression along the major portion of its length is less than 600 feet above sea-level, and only at the col connecting it with the limestone country to the east of the Dent Fault does it ever rise beyond the 900-foot level. Before the diversion mentioned above the whole of the depression along this boundary was drained by waters carried to the Lune by way of Ravenstonedale and the main valley on the north and west, and by the Rawthey on the south-east.

Geologically the Howgill tract is almost as well-defined as it is geographically. On the west side, it is true, the strata extend across the Lune from the Howgill Fells to the fells west of that river, and the division is only physiographical; but on the north and south-east sides it is practically defined by the line of junction between the Silurian and the Carboniferous rocks, though some of the older rocks extend across the Rawthey to form the flanks of Baugh Fell beyond the limits of the Howgill Fells.

The Howgill Fells, then, consist essentially of Silurian rocks (with inconsiderable patches of Ordovician strata in the neighbourhood of Rawthey Bridge). These rocks are referable to the divisions known as Stockdale Shales, Coniston Flags, Coniston Grits, and

Bannisdale Slates, but the main mass is composed of the slates of the two last-named divisions, which, notwithstanding their different names, have much in common; and, as will be shown later, the uniformity of character of the rocks is of great importance in determining the physiographical features of the fells.

The general relationship of the Howgill Fells to the surrounding tracts and the cause of the severance of these Fells from those to the west of the 'gorge' of the Lune have been considered by one of us elsewhere,[1] and need not here be discussed. From our present point of view the important point is that the Fells constitute a monoclinal block, with its dip-slope on the north and its scarp facing south, though both dip-slope and scarp are shortened at the eastern end owing to the trend of the Dent Fault.

Accordingly, could we but fill in the hollow spaces produced by valley-erosion, we should find the Fells presenting a 'desk'-structure, with the gentle long slope to the north and the short sharp drop to the south. The summit-ridge ranges east and west at a height of about 2000 feet quite close to the southern edge. There is evidence that at one time the watershedding ridge lay much nearer the southern and farther from the northern margin of the tract. (See Pl. XXIX.)

If the junction of the Carboniferous and Silurian rocks were continued over the summits of the Howgill Fells, where the former have now been removed, it would appear as a gently sloping plane not far above the tops of those hills. At present, the lowest Carboniferous rocks occupy the Ravenstonedale Valley north of the Howgills; they are seen to rest on the northward continuation of the hills themselves, and have a dip which is sufficient to carry them over all the hills. The base would, if continued along the present dip-plane, carry them some hundreds of feet above the fell-tops. The sudden increase of slope of the surface, however, as it approaches the Carboniferous rocks seems to indicate that there was there a monoclinal flexure, and that the dip became much higher to the north: hence it is probable that the present surface, if the valleys were filled in, would coincide fairly closely with the original base of the Carboniferous strata.

South of the Fells a continuation of this dip would carry the Carboniferous some hundreds of feet above the River Rawthey; whereas, in fact, for a distance of more than 3 miles the 'Basement Carboniferous Conglomerate' actually occupies the valley-bottom in the neighbourhood of Sedbergh, where it is let down by a great fault. The steep southern face of the Howgill Fells is determined by this fault, which trends south of east to west of north. But the fault is not simple: the Geological Survey map shows three faults parallel to that which brings in the Carboniferous of the Rawthey Valley against the Silurian of the fells. These are probably step-faults, and the northernmost of them which occurs behind Winder Crook and the Knott is no doubt responsible for the shelf

[1] Quart. Journ. Geol. Soc. vol. lxii (1906) pp. xcvi–xcix.

of dip-slope which is preserved upon these hills at a much lower level than that beyond the summit-ridge to the north.

Another fracture apparently occurs north of the main watershed, crossing the district from west to east from the Carling Gill Valley to Ellergill Sike, forming a step in the dip-slope, and by its shattering determining a row of cols more or less parallel to the main watershed.

The shatter-belt[1] of this fault is very wide, and is marked along its course by hæmatite staining, probably introduced from above when the basement-conglomerate covered the tract.

The section drawn from the Calf to the river Lune along the hill-tops west of Bowderdale (Pl. XXXI, fig. 2) shows the character of the displacement and the general characteristics of the old Pre-Carboniferous dip-surface in this district.

The movement which caused the present elevation of the Howgill Fells, the nature and age of which have been referred to by one of us elsewhere,[2] was apparently so widespread that it caused but little warping of the northern Carboniferous dip-slope just discussed, and the consequent displacement of the Silurian platform may here be neglected. As the basal Carboniferous rocks were removed, the bared Silurian rocks must have appeared in the form of the monoclinal block in which we now find them.

On whatever rocks the rivers developed upon the Howgill tract were initiated, the retardation of erosion when Silurian rocks were encountered would be so considerable that the streams occupying the thalweg of the waters in the Ravenstonedale Valley, along the soft rocks of the basal Carboniferous, must have lowered that tract considerably before the Howgill streams could accomplish much erosion.

Similarly the Rawthey was eroding in weak rocks, and the Lune south of Tebay perhaps keeping open its course along a line of weakness during uplift. Consequently the triangular stretch of what is now low ground surrounding the Howgill Fells was lowered, leaving the upland monocline in its midst. Upon this central block of the Howgill Fells, the drainage-lines were therefore determined by (*a*) the ridge between dip-slope and fault-scarp as watershed, and (*b*) the three depressions of Ravenstonedale, the Lune below Tebay, and the Rawthey Valley and its northern feeder Sally Beck, which extends to a col looking over to Ravenstonedale.

A series of long streams were developed on the dip-slope and flowed northwards. Of these, Tebay Gill and Ellergill and some

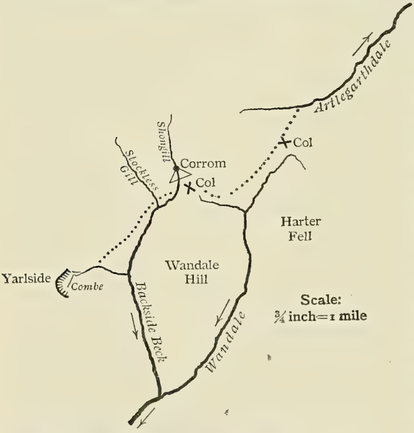
[1] I have elsewhere described a series of shatter-belts as occurring among the Lower Palæozoic rocks of Lakeland, along tear-faults; but the term was not then defined, and there is no reason to confine it to the shattered tracts along tear-faults. I may define a shatter-belt as 'a belt along which the rocks have been shattered by movement into large and small fragments, the rocks on either side not necessarily being permanently displaced, although they are frequently so displaced.'—*J. E. M.*

[2] Quart. Journ. Geol. Soc. vol. lxii (1906) pp. xcvi–xcix.

minor streams rose somewhat to the north of the main watershedding line, but the streams of Uldale, Langdale, Bowderdale, and Artlegarthdale all rose upon that line. Owing to the gentleness of the slope all these streams had low grades. South of the main watershedding line, on the short scarp-slope, brief steep-graded streams flowed southwards to the Rawthey, namely, Hobdale, Cautley, Backside, and Wandale Becks; and the steep side towards the Lune south of Tebay was also drained by the short and steep Carling Gill and Blands Gill and their tributaries.

The early dissection of the monoclinal block-tract was produced by these streams and their tributaries; but, as the northward flowing streams are near together, their tributaries are unimportant, and hence the ancient surface of the Silurian platform is preserved on the divides between the streams with but little change.

Fig. 1.—*Plan illustrating the drainage of Backside and Wandale Becks and Artlegarthdale.*



[The dotted line indicates the direction of the former drainage.]

Modifications of the drainage are due to the tendency of the short swift streams flowing to the Lune south of Tebay and to the Rawthey on the south of the fells to cut back into the watershed, and to capture the head waters of the northward-flowing streams.

Beginning at the north-west, and working southwards and then eastwards, we find that the first important captures are made by Carling Gill. The head of Tebay Gill remains intact; but that of Ellergill next to the east has been cut off, and a col connects it with Carling Gill. The most striking capture, however, by Carling Gill is that of the Black Force stream and of the head of Uldale. Farther south another of the westward-flowing streams, Longrigg Beck, has cut off the heads of two of the tributary streams of another Ellergill, which flows to the Lune. A feeder of Longrigg Beck has also beheaded West Grain Beck, a tributary of the northward-flowing Langdale Beck, and has so produced the col known as Wind Scarth Wyke.

None of these captures, save that of Great Ulgill and the Black Force (Little Ulgill) streams by Carling Gill, are of any serious importance.

In the south the southward-flowing streams have not yet cut through the western part of the watershed. In the east, however, the monoclinal ridge has been much cut into, and very important captures have resulted. Of these the most pronounced is that made by the Cautley stream, and the robbery of the waters that once flowed into Artlegarthdale by Backside and Wandale Becks (see fig. 1, p. 590).

The steeper grades of the capturing streams would, no doubt, have caused all these captures to occur in time. As it is, there is evidence of the acceleration of some by glacial agency, which renders them of particular interest, and the whole evidence will be considered when the glaciation is described.

The pre-Glacial Condition of the Howgill Tract.

The erosion by the various streams had already dissected the monoclinal highland in pre-Glacial times. As before seen, the conditions produced north of the watershed were such that the streams left ridges with summits sloping gradually down northwards from the watershed and with few definite minor summits along the ridges. On the south side, where conditions were much more complex, actual hill-summits are found: such are Arant Haw, Calders, Yarlside, Wandale Head, Harter Fell, and others.

A great feature of topographic interest in the glaciology of the Howgill District is, that while some of the valleys are clearly much ice-worn, others bear no sign of glacial erosion, and consequently the effects of stream- and of ice-erosion can be compared or contrasted within a limited space.

The study of valleys not appreciably affected by ice gives an idea of the effects produced in this district by stream-erosion. The best examples of such valleys are occupied by the feeders of Bramrigg Beck. These valleys show well-marked V-shaped outlines with slightly convex slopes, culminating at the head in slightly rounded ridges and summits. At present, their slopes are entirely clothed with vegetation, as also are the summits, and this tract presents outlines like those figured by Prof. W. M. Davis in the Scottish Geographical Magazine for 1906, in fig. 1 of his paper on 'The Sculpture of Mountains by Glaciers.'

No cliffs with exposed rock and no abrupt changes of slope are seen in these and similar valleys of the district. There is no doubt that their monotony of outline is due to the similarity of the behaviour of the component rocks of the hills as regards weathering. We have already noted that the Fells are chiefly composed of Coniston Flags and Grits and of Bannisdale Slates. These rocks are greywacké grits and mudstones, which are usually well jointed and break into small pieces. Moreover, owing to the nature of the

binding material between the grains, these grains become separated in the course of weathering; and grits, slates, and mudstones all behave similarly, giving rise to a thin soil on which vegetation flourishes and prevents the downward carriage of fragments by surface-water runnels. The material is being gradually removed by soil-creep among the vegetation and superficial detritus.[1] It is doubtful whether in times immediately preceding the Glacial Period any rock was exposed, save only in the stream-courses; and the evidence points to the production of the present rock-exposures on the hillsides in three ways:—(1) by truncation of spurs by ice; (2) by corrie-glacier erosion[2] in the combes; and (3) by the post-Glacial erosion of captured streams adapting themselves to their grades.

Glaciation of the Fells.

Our study of the ice-work of the Howgill Fells area leads us to adopt generally the views of the late Mr. J. G. Goodchild, as described in the letter-press and indicated on the map accompanying his paper.[3] We regard the Howgill Fells as an independent centre of glaciation, the ice-field of which covered nearly the whole area and had an ice-shed agreeing with the present watershed. From this the ice flowed down the three slopes of the triangle, northwards to the Ravenstonedale depression, westwards to the Lune, and southwards to the Rawthey Valley. This ice-sheet united in the north with that which came from the Lake District to pass eastwards over Stainmoor; on the west with that which came over Shap Fells; and on the south with that which, originating on the uplands of Baugh Fell and Wild Boar Fell, extended thence down the valley of the Rawthey.

The distribution of the drifts suggests that the ice filling the three depressions acted as follows:—In the north, the Howgill ice in the Ravenstonedale depression was, save at the western end, able to push back that of the Lake District to the north of that depression. On the west, the Lune ice held its course from Tebay as far south as Carling Gill. It was then pushed aside by the Howgill ice and driven through the depression which the railway follows from Lowgill to Grayrigg towards the Kent Valley. On the south, the ice of Wild Boar and Baugh Fells kept the local ice from the short scarp-face from getting a footing in the Rawthey valley, diverting it to the westward, and in one place to the north-eastward. Reasons for these views will be stated subsequently.

[1] See J. E. Marr, 'The Origin of Moels & their Subsequent Dissection, Geogr. Journ. vol. xvii (1901) p. 63; also G. Götzinger, 'Beiträge zur Entstehung der Bergrückenformen' Penck's Geographische Abhandlungen, vol. ix (1907) pt. 1.

[2] After reading Willard D. Johnson's paper in the 'Journal of Geology' (Chicago) vol. xii (1904) p. 569, we would go further and speak of Bergschrund erosion.

[3] 'The Glacial Phenomena of the Eden Valley & the Western Part of the Yorkshire Dale District' Quart. Journ. Geol. Soc. vol. xxxi (1875) p. 55 & pl. ii.

(A) Glaciation of the Lowland Tracts around the Howgill Triangle.

(1) The Ravenstonedale Lowland.—Examination of Goodchild's map in the paper cited shows the line of the approximate southern limit of the Shap Granite boulders and the eastward trend of the ice which carried them. There is little doubt that these boulders were kept from passing southwards by the Howgill ice which was emerging from Langdale and the valleys on the east, which, as far as Artlegarthdale, are filled with drift charged with Howgill boulders. But Tebay Gill is filled to the head with drift from the north, containing boulders of Carboniferous rock, Shap apophyses, and occasional boulders of the parent Shap Granite. (One actual fragment of the last-named, an inch and a half in diameter, was taken from a clay-bank near the head of Tebay Gill; and a large mass, 6 feet in diameter, may be seen close to the mica-trap, half a mile east of Tebay railway-station, in the stream, and many others of less notable size abound in the same neighbourhood.) A thermally metamorphosed mass of Yarlside rhyolite was also observed. Ellergill has Carboniferous boulders a long way from its mouth, and possibly all the way to its head. It will be noticed that both Ellergill and Tebay Gill are short and comparatively unimportant valleys, which start far north of the main watershedding line of the Fells.

The ice which filled the Ravenstonedale depression was responsible for the formation of the gorge through which the Smardale stream flows: the Smardale Gorge is, in fact, a marginal overflow. (In a paper published in the Proceedings of the Geologists' Association, vol. xx, 1907, p. 147, one of us did not accept the idea of a marginal overflow from ice, but during a subsequent visit was convinced by Prof. W. M. Davis.) A similar overflow occurred in a tributary valley from Sunbiggin Tarn, and another to the east of Ashfell Edge; but these have not produced any marked deflection of the drainage. We are not, however, concerned with marginal overflows in the present paper.

(2) The Lune-Gorge Lowland.—That ice from the Lake District flowed some way down the Lune gorge is shown by the fact that boulders of Shap Granite and apophyses have been noted by Prof. Hughes at the foot of Carling Gill, and boulders of the apophyses have been found by us as far as Lincoln's Inn Bridge. A boulder of the granite was also noted at the bridge, but may have been carried down by the stream. The scarcity of these boulders shows, however, that the Lune ice was diverted south-westwards, as maintained by Mr. Dakyns and in the Geological Survey Memoir.[1] That the ice coming from the Howgill Fells (especially through the

[1] 'The Geology of the Country around Kendal, Sedbergh, Bowness, & Tebay' Mem. Geol. Surv. 1888, p. 49.

RawtheyValley) was more powerful than the ice coming down the gorge, is indicated by the direction of the drumlins in the fork where the two valleys meet. The Howgill and Rawthey ice there pushes its drumlins well out into the gorge. The Lune gorge is well glaciated: it is a marked U-shaped valley with well-truncated spurs, which give much of its sides a rocky character. On the west side is a hanging valley forming the northern half of Great Combe, and the rest of that combe was apparently enlarged by a corrie-glacier. The truncated spurs may be well seen; from view-points about Tebay, or between that village and Low Borrow Bridge; and below them the valley has been to some extent deepened by ice. Subsequently, however, that part of the valley was filled with Boulder Clay which is now being excavated by the river, but still forms a marked terrace on each side of the valley, where the flatter lower portions of the old catenary drift-slopes remain undenuded. Towards Sedbergh the Lune Valley drift is less regularly arranged than it is to the north of Lowgill: for this part of the valley was the dumping-ground for terminal morainic material.

(3) The Rawthey Lowland.—The Rawthey Valley is wide and, on the whole, flat-floored. The north side, forming the scarp-face of the Howgills, is characterized by admirable truncated spurs on all the hills between the Lune and Rawthey Bridge. These, when viewed from near Sedbergh railway-station, are well seen on Winder and Crook, where the change of slope and the rocky character of the spurs is clearly exhibited. But, although these spurs afford testimony of the widening of the valley by ice, there is little evidence of serious overdeepening by the same agency. Much drift, however, still lies in the valley concealing a great portion of the floor, and this may, to some extent, mask overdeepening.

(B) Glaciation of the Valleys of the Howgill Highland.

It will be convenient to treat these valleys in order, according as their waters flow to the Lune Gorge, the Rawthey or the Ravenstonedale Lowland. We will begin with the valleys tributary to the Lune Gorge.

Two small valleys occur on the east side of the Lune, between Tebay railway-station and Carling Gill. They do not appear to have been glaciated, but are filled with deltoid masses of drift (save only where subsequently cleared out by post-Glacial stream-erosion); and the drift runs continuously with that of the Lune-Valley terrace, forming the upper part of its catenary slope. This drift appears to have been deposited by Lune ice moving transversely and at right angles to these valleys.

Deltoid masses of drift occupy the bottoms of many of the minor valleys. The apex of the delta is towards the valley-head, and the drift slopes with a fairly uniform grade towards the foot—the surface being nearly plane, or forming a slight catenary in cross-

section. The margins of the drift at the valley-sides are usually well defined.

The deltoid drift-masses seem to occur when the ice has moved up-valley or transversely thereto, or has flowed over a col into another valley, thus suggesting that they are due to the melting of inert ice.

Going southwards, we now arrive at the important valley of Carling Gill, the waters of which rise on Fell Head. For more than a mile up from its junction with the Lune, the Carling Gill Valley is wide and U-shaped with truncated spurs, and shows the glacial scooping of which we speak as 'conchoidal' on the concave sides of its bends.[1] One of the best of these scoops is seen on the southern bank of the stream west of Green Knott Gill.

There is much drift on the valley-floor. A deltoid mass of drift cut through by Grains Gill and the lower part of Weasel Gill contains Carboniferous boulders and is traceable up to, and beyond the col which marks the beheading of Ellergill, into the valley of the latter stream. It is clear that the ice which, as before stated, filled Ellergill from the north also gave rise to this delta, which must have been left by a tongue of northern ice coming through the col.

The top of the U-shaped part of Carling Gill is at a point south of Uldale Head. Here Carling Gill once had three heads. That on the north from Uldale Head (Great Knott Gill) is now marked by a U-shaped valley, with a combe at the head and a deltoid mass of drift below. Small Gill on the south side is also a well glaciated U-shaped valley with much drift, and ice may have traversed the pass at its head to Fair Mile Beck on the south. Traces of a third head are also seen in the slightly modified slopes west of Black Force; but the shape of the ground shows that there ice-erosion has had but little effect. It is into this central head that the streams which have been diverted into Carling Gill flow.

Dr. Strahan detected the diversion of the old Uldale waters into Carling Gill, but does not notice the deflection of those of the Little Ulgill Beck Valley which forms Black Force. In the Geological Survey Memoir ('The Geology of the Country around Kendal, Sedbergh, &c.' 1888, pp. 45–46) he writes

'In the head of Uldale a remarkable instance of the intersection and tapping of the water of one dale through the eating back of the head of another has been observed. It will be seen by the distribution of the Drift that the Uldale Valley starts under Wind Scarth and crosses the County Boundary. The hills forming the west side of the valley, however, are breached at the County Boundary by a deep and rocky but narrow ravine, by which the water collected under Wind Scarth finds its way direct to the Lune at Carlingill, instead of following the Uldale Valley to Gaisgill. There can be little doubt that originally Uldale formed a continuous line of drainage up to the foot of Wind

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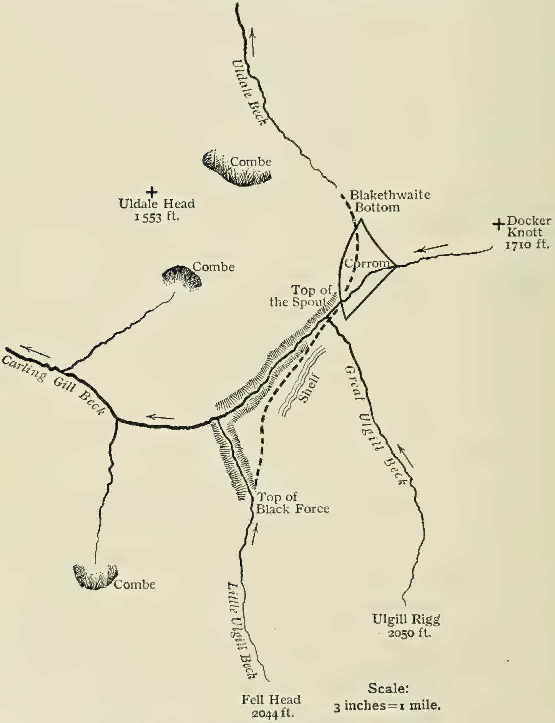
[1] This term is used, because the ice gives rise to concave scoops recalling the appearance of the inner side of the valve of a clam-shell.

Scarth, and that the diversion of its head waters has been due to the cutting-back action of the head waters of the Carling Gill. A small dam would even now be sufficient to turn the waters back to their old course. The date at which the change took place is uncertain. The rocky ravine referred to is altogether devoid of Drift, but this may merely be the result of the rapid erosion that is taking place, and not necessarily a proof that the ravine is of post-Glacial origin. It seems hardly likely that so deep a cut can have been made in solid rock within the post-Glacial period.'

Fig. 2.—*The Carling Gill-Uldale diversions.*



[The broken line indicates the former drainage.]

The accompanying diagrammatic plan (fig. 2) illustrates the physical features here and our explanation of them.

There is no doubt that in pre-Glacial times the Carling Gill stream was almost ready to behead Little Ulgill Beck below the site of what is now Black Force. The slopes on the south side of Green Knott (a shoulder of Uldale Head) and on the opposite side of Carling Gill indicate the existence of a curved valley-head (the middle head above described), which cannot have been separated from Little Ulgill Beck Valley by more than a few score yards, and it was much more deeply cut than was the latter valley. The valley above Black Force is well glaciated, U-shaped, and with much drift which is now spilt over Carling Gill north-east of Black Force, owing to the subsequent capture of Little Ulgill Beck by Carling Gill. The evidence is, on the whole, in favour of the ice in Little Ulgill widening that valley to a sufficient degree to cut through the ridge between it and the middle head of Carling Gill, at which time ice- and moraine-matter was spilt over into the deeper Carling Gill. After this occurrence, and after the recession of the ice, the waters of Little Ulgill Beck, following the ice-course, have cut out the water-carved gorge of Black Force, which is 590 feet high from top to base, the old valley being one of the most striking hanging valleys in the North of England, especially as seen from Green Knott.

After this capture, the further capture of the Great Ulgill Beck discussed by Dr. Strahan was a small matter. The old beheaded valley would be dry as far down as the point of incoming of the next tributary, the waters of which would therefore tend to build out a delta across the main valley. This delta would grow to a height sufficient to direct the waters along the dry valley to a point where they could get across to the Carling Gill drainage. This has been done, and, owing to the increased grade, a deep cut has been made here also (at the Spout), though not with so marked a waterfall as at Black Force. It must be noted that this cut is partly in the old course of the curved middle head of Carling Gill, and that, therefore, the amount of post-Glacial erosion is not so great as Dr. Strahan suggested. The cañon-like character of the gorge, with its overlapping spurs and rocky precipices, indicates its post-Glacial formation. Traces of an old shelf on the left bank of the gorge mark the old east side of the valley-floor of Little Ulgill.

The diversion by delta-growth described above is actually seen in the process of diverting the next tributary down-stream into Carling Gill at Blakethwaite Bottom, and in a few years will probably be complete. At the time of our visit, the stream from Docker Knott was flowing over the south side of the delta into Carling Gill; but a dry channel in the delta-material, northwards into Uldale, may in time of flood take back the bulk of the waters in that direction, although of course the growth of the delta will eventually send the stream always the other way and a further stretch of Uldale will be permanently dry, and so prepare the way for another growth of delta by a tributary farther down stream, and yet other captures of the Uldale tributaries by Carling Gill. This

successive diversion by delta-growth of the downward tributaries of beheaded streams (however beheaded) must be a common feature, and we shall deal with another case in our district.

Cases of these delta-watersheds are described under the name of 'corroms' by Prof. P. F. Kendall & Mr. E. B. Bailey in their account of 'The Glaciation of East Lothian South of the Garleton Hills.'[1]

Fig. 3.—*The corrom: Blakethwaite Bottom, looking east.*

[The stream to the south of the corrom flows into the Spout.]

The old head of the valley below Ulgill Rigg is well glaciated, there being a Glacial combe there. Some of the ice possibly went over the col between Bleagill Head and Taffergill into the combe at the head of Churn Gill; but the main part went down the old Uldale Valley, though apparently it produced but little erosive effect, except in the combe at its head, depositing, however, a considerable amount of drift in the valley.

The lower part of Uldale, discharging northwards, will be described in its proper place.

South of Carling Gill is Fair Mile Beck, rising in two tributaries on the west side of Fell Head. The valley is a U-shaped valley, and its tributaries are also U-shaped, a small corrie-moraine occurring at the base of a small combe at the head

[1] Trans. Roy. Soc. Edin. vol. xlvi (1907–1908) p. 25.

of the southern tributary. Drift occurs on the col between the northern tributary and the Black Force valley, where, as already stated, a tongue of ice probably went over into the valley from Fair Mile Beck.

Proceeding southwards, we come to Ellergill (which must not be confused with the two valleys of the same name to the east of Tebay). It is a U-shaped valley, with much drift filling the floor. The disposition of this drift indicates that a lobe of ice came over the col north of Brown Moor (produced by the beheading of this Ellergill by Longrigg Gill), hence the U-shaped excavation of this comparatively short valley. Half a mile below the col, the occurrence of Lune Valley drift with Shap Granite apophyses, at a height of over 800 feet, shows that the Lune ice came over Whin End into Ellergill.

The next stream to the south is important. It is named Blands Gill on the 1-inch, and Chapel Gill on the 6-inch Ordnance Survey map. It has several feeders: the most important of these is Longrigg Beck, which rises on the south side of Ulgill Rigg, with a branch from Wind Scarth Wyke (which has beheaded a tributary of the north-flowing Langdale Beck). The head of Longrigg Beck is marked by a combe, and the valley is no doubt widened by ice, being U-shaped from the start. About a mile from its head it receives Longrigg Gill, which rises in a rocky combe on Fell Head, and flows through a markedly U-shaped valley that hangs some way below the combe. This hanging head of Longrigg Gill was probably at one time the head of the Ellergill valley, but was beheaded by the cutting through of a former ridge between Brown Moor and Longrigg in pre-Glacial times. The valley below this junction of the Beck and Gill is floored with drift. It retains its U-shaped outline and cross-section down to the low ground of the Lune Valley. A third of a mile below the confluence of Longrigg Gill, another stream (Calf Gill) joins Longrigg Beck, flowing from the east and rising on the highest plateau of the Howgill Fells. The Calf, from which the beck takes its name, is the summit of this plateau, and rises 2220 feet above sea-level. This valley has also suffered much from Glacial erosion, is again markedly U-shaped, and starts in a fine combe with morainic material at its mouth, just beneath the Calf.

On the west side of Longrigg Beck, opposite the entrance of Calf Gill, is a rocky hill, Castley Knotts, which, since we find moraines of drift sweeping in drumlins round its southern face, and crossing Longrigg Beck at a height of about 890 feet, was probably at one time completely overridden by Lune Valley ice. On the east side of the beck, 200 yards above the entrance of Bramrigg Beck, the stream has cut a fine section in the drift. This section shows about 20 feet of local stratified drift containing no foreign boulders,

resting upon 40 feet of stiff unstratified Lune Valley drift, with boulders of Shap apophyses, Carboniferous Limestone, and basement Carboniferous conglomerate: similar drift is seen in a section made by Bramrigg Beck, a few yards from its entrance into Longrigg Beck, and above a waterfall.

Bramrigg Beck comes in also from the east. This beck rises in a slight combe between Bramrigg Top and Calders, about a sixth of a mile south of the source of Calf Beck; but the valley is essentially waterworn. As far as the influx of the unnamed stream from Rowntree Grains it is typically V-shaped. The two

Fig. 4.—*A V-shaped valley near Arant Haw, looking towards the head.*

stream-heads of the tributary from Rowntree Grains have no combes, and are also strictly V-shaped. They furnish admirable examples of the outlines of valleys which have not been affected by ice-erosion: doubtless ice formed in them, but was not effective for erosion. Below the junction of the two forks, the V-shaped cross-section is slightly modified by a conchoidal scoop on the concave south side of the valley. Below the junction of this valley with Bramrigg, the latter becomes more powerfully affected by ice, and is intermediate between a typically V-shaped waterworn valley, and one of U-shape modified in a high degree by ice. It has a truncated spur on its southern side.

Two-thirds of a mile below the junction of the nameless tributary,

Swarth Greaves Beck enters Bramrigg Beck from the south-east. It rises on the slopes of Arant Haw, and like the last tributary is curved with the concave side to the south. It is very slightly modified by ice-erosion in its upper part, being essentially V-shaped, but has a conchoidal glacial scoop on the concave side lower down. As seen from Fell Head, the conchoidal scoops in these valleys show up well: the south-western sides of the ridges and their summits being convex, and the north-eastern sides concave.

Bramrigg Beck Valley was deepened by ice to a greater extent than that of Swarth Greaves Beck. Accordingly we find the latter valley hanging slightly, and a rocky gorge with a waterfall at its head is developed, owing to the subsequent tendency to adjustment of grade. The same features are noticeable in Bramrigg Beck itself a few hundred yards lower down, where a small gorge and waterfall mark the greater deepening by ice-erosion of Longrigg Beck Valley.

Over a mile south of Blands Gill is Crosdale Beck, rising on the south-western side of Arant Haw. The valley is emphatically straight and U-shaped, with truncated spurs on both sides. It has a straight course of 2 miles to its junction with the Lune. A tributary from the north (Combe Gill), rising in a combe, is also U-shaped. A deltoid mass of drift occurs near the head of Crosdale Beck.

This is the last stream that flows directly into the Lune, for the next stream in order enters the Rawthey.

Before leaving these streams, it should be noticed that, although they are clearing out the low-level drift of the Lune Valley in the lower part of their courses, they elsewhere flow in series of cascades over solid rock and are engaged in grading their beds to normal courses after the disturbance produced by the Glacial widening and over-deepening of the Lune Valley.

We now pass to the consideration of those valleys, the streams of which are tributary to the Rawthey, and shall take them in order from west to east.

The first stream, Settle Beck Gill, rises on the dip-shelf between Winder and Crook, and from its source falls steeply southwards, there being a difference in level of about 1000 feet in the mile between the source and the point where it reaches the low ground of the Rawthey Valley. It has been filled to a great depth with a deltoid mass of stiff drift containing well-glaciated boulders: the upper surface of this mass slopes almost uniformly downwards until near the Rawthey, where it joins the drift of the Rawthey Valley with a diminished slope. The stream is now clearing out the drift, as described in the Geological Survey Memoir, and is cutting between the drift and the solid rock, leaving a wide shelf of drift on the western side. The boulders in the higher parts are of local origin; but at a height of 800 feet above sea-level, and over 400 feet above the Rawthey at the junction of Little Gill, Carboniferous boulders occur, showing that the Rawthey ice rose

at least as high as this. The phenomena developed here are in part like those of the two gills north of Blease Fell, south of Tebay, where the ice was also moving at right angles to the tributary valleys.

Similar features are seen in the next valley to the east, Ash Beck Gill, which rises on the south-east side of Arant Haw and runs southwards to the Rawthey between Crook and Sickers Fell. They are seen also on a smaller scale in Little Ash Beck, between Sickers Fell and Knott. The appearance suggests that a tongue of ice flowed from the next valley to the east (Hobdale Beck), over a col behind and north of Sickers Fell, to the head of Ash Beck Gill, and thence over a col behind Crook to Settle Beck Gill. Hence Crook and Sickers Fell may have stood out as 'nunataks' between this ice and that of the Rawthey, though it is more than probable that at the time of maximum glaciation the confluent ice-masses also covered the fell-tops mentioned. Another tongue from the Hobdale Valley seems to have flowed through the col between Sickers Fell and Knott into Little Ash Beck.

It is very doubtful whether any ice-erosion occurs either in the Settle Beck or in the Ash Beck valleys, owing to the passage of ice at right angles. Appearances indicate that, if the drift were cleared away from them, they would show V-shaped cross-sections.

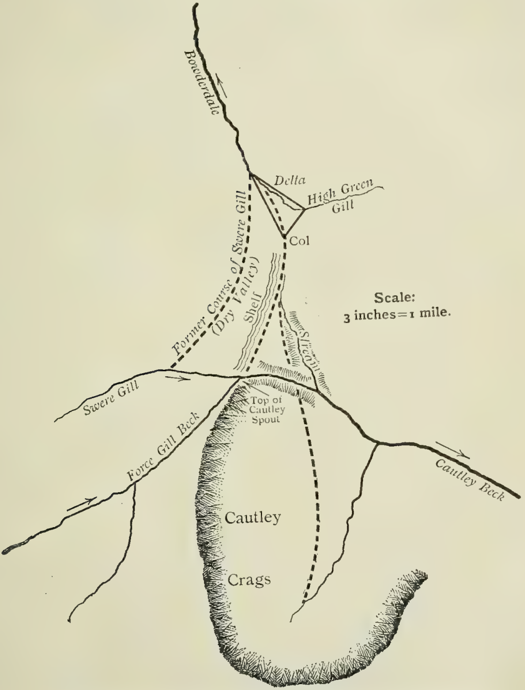
The Hobdale valley is of greater size than those last mentioned. Hobdale Beck rises in a combe below Calders (2200 feet) and flows southwards through a U-shaped valley with the truncated wrecks of overlapping spurs. It has a curved course with a concavity to the west where, below Hobdale Scar, there is a Glacial scoop to which the scar is due. Below this, the ice-tongue already mentioned crossed behind Sickers Fell and between Sickers Fell and Knott. About a mile below its source Hobdale Gill receives Grimes Gill, the source of which is not far from that of Hobdale Gill. It flows down the east side of Middle Tongue with a concavity on the east. In the upper part of Grimes Gill there is but little sign of glaciation, save in the conchoidal scoop on its eastern side and in the large landslip which (probably determined by Glacial steepening of grade) has slipped forward from its western side. Below the landslip a moraine occurs. Lower down, the valley is V-shaped, approximating to the U-shape. The upper part of the valley has local drift, but at the 800-foot contour the presence of Carboniferous boulders shows that the Rawthey Valley drift has been reached; and, owing to the Glacial widening of the Rawthey, the stream cuts through the deltoid drift-mass with increased grade. The ice of Hobdale was probably rendered nearly inert by the pressure of this Rawthey ice.

Between Hobdale and Pickering Gill, drift occurs on the west slopes of the Rawthey to a height of 1200 feet, plastered against a

truncated spur immediately south of the latter gill. A snow-slope 'moraine' crosses this gill high up.

We are now in the drainage of Cautley Beck, which Pickering Gill joins just before the former beck flows into the Rawthey. Cautley Beck occupies a wide U-shaped valley, the lower part of which is graded to the Rawthey. This beck presents an admirable example of a series of captures which, beginning in pre-Glacial time,

Fig. 5.—*The Cautley-Bowderdale diversions.*



[The broken lines indicate the former course of the drainage.]

have continued through Glacial time to the present day. The phenomena displayed are only explicable on the supposition that Bowderdale Beck (which flows northwards in a valley to be described later) once arose in two tributaries on each side of the plateau known as Great Dummacks, over 2150 feet high. The drainage

of both these tributaries and of another on the north, Swere Gill, is now into Cautley Beck. On the east side of Great Dummacks is the most marked rocky combe in the Howgill Fell tract, backed by Cautley Crags. The combe faces eastwards, but a large semicircular recess at its southern end faces northwards, that is, in the direction of the beheaded Bowderdale. The stream from the west side of Great Dummacks, called Red Gill Beck, flows for a mile towards Bowderdale in a well-graded valley, the grade of which is continuous with that of Bowderdale. Shortly above Cautley Spout, however, it enters a gorge, and in the distance of about a sixth of a mile plunges in a series of continuous cascades down 600 feet of vertical height, forming the Spout or waterfall at the northern end of Cautley Crags.

The eastern wall of the southern recess of Cautley Crags is continued as a rocky spur, becoming truncated when 300 feet above the valley-bottom; and a corresponding truncated spur topped by a landslip occurs opposite on Yarlside, at a similar height.

This arrangement points to a former ridge right across the Cautley Valley, separating it from the former head of Bowderdale. This ridge must have been sawn through in pre-Glacial times, or in very early Glacial times: if in the latter, possibly as the result of a marginal Glacial overflow. The old spurs of this ridge have subsequently been truncated by the ice, which accumulated in the former head of Bowderdale: this has produced the great combe by glacial erosion. The ice has left a number of parallel moraine-mounds on the valley-bottom below the truncated spurs, extending for about half a mile down stream; and there is a shelf in the combe above the 1250-foot contour-line with terminal moraine upon it, left when the ice had shrunk to a corrie-glacier.

Red Gill Beck, before its plunge down Cautley Spout, has a wide valley; but the gentle slope on the south is cut away at the ridge by the rocky precipice of Cautley Crags. It is obvious to the observer on the spot that the recession of the combe by ice-erosion (with the accompanying landslip and frost-work above) has cut away the side of the valley nearer and nearer to the stream as it flowed north-westwards, until at last the whole of the side was removed, and the post-Glacial stream compelled to plunge down Cautley Spout, which it has carved into a waterworn gorge showing no trace of glaciation. Subsequently to this, the capture of Swere Gill has occurred. High Green Gill still drains into Bowderdale, but has built a delta almost to the col-level. This delta will soon become a 'corrom,' and will divert High Green Gill into Cautley Gill. The changes which have here occurred recall those of Carling Gill and Uldale Gill, although there are considerable differences in detail.

We now approach a tract of country, complex alike in the character of its river-captures and in its glaciation. It is drained on the south side by Backside Beck, Wandale Beck, and Sally Beck, the last-named here forming the boundary of the Howgill Fells and running practically along the Dent Fault.

From Yarlside on the west of Backside Beck a wide depression runs behind Wandale Hill to Adamthwaite and thence to Artlegarth Beck which drains to Ravenstonedale. This depression is essentially one valley, with its southern wall breached at two places by the narrow valleys of Backside Beck and Wandale Beck. That the Wandale breach was the earlier is indicated (1) by the lowering of the col between Backside Beck and Wandale Beck to a depth of 70 feet below that between Wandale and Artlegarthdale; (2) by the steeper grade of the Wandale Valley, the 1000-foot contour being far nearer to the head of Wandale than of Backside; and (3) by the recent diversion of Spengill from Wandale Beck into Backside Beck by a 'corrom,' showing that the tract where the delta occurs has been but recently dried by the beheading of the upper waters of the Backside stream, known as Stockless Gill. It will be seen from the plan (fig. 1, p. 590) and the section (Pl. XXXI, fig. 1), that Watley Gill, Stockless Gill, and Spen Gill now flowing into Backside Beck, and Adamthwaite Sike and Stoneley Gill, tributaries of Wandale Beck, all have their upper waters directed towards Artlegarthdale: the latter case is especially clear, as its upper part forms a hanging valley (as do the others in a less marked degree) and its waters flow at first northwards, but bend round through west to south to reach Wandale. The 'corrom' diversion of Spengill into Backside Beck has caused the latter to cut the well-known section in the Stockdale Shales while grading itself to its new conditions.

Turning now to the glaciation, two points in the physiography of the region must be noticed. First, the hills east of the Backside valley are much lower than those farther west; and, owing to the obliquity of Sally Beck and the Rawthey to Ravenstonedale, this part of the upland is much narrower than on the east. Secondly, the Fells of the high ground south of the Rawthey are nearer the Howgill Fells and higher than those farther west. There was, therefore, a great gathering-ground of ice in the amphitheatre in which the head waters of the Rawthey arise on the south between Baugh Fell (2216 feet), Swarth Fell (2235 feet), and Wild Boar Fell (2324 feet). Goodchild takes his ice-shedding line over this tract, and inserts on his map striæ running nearly due north over the col between Wandale and Artlegarthdale on the west side of Harter Fell. That ice carried material over in this direction is indicated by the presence of Carboniferous Limestone boulders on the west side of Sally Beck, above Low Spout Gill, at a height of about 1000 feet; also by the presence of boulders of Millstone Grit at the same height in Wandale near Adamthwaite, above the 1250-foot contour-line over the watershed in Gaisgill, the head of Artlegarthdale, and, lastly, on the 1200-foot line near the head of Wyegarthdale.

The Baugh Fell–Wild Boar Fell ice must have filled Wandale and Sally Beck, either leaving Harter Fell as a 'nunatak,' or at the time of maximum glaciation covering it, and going some way up the Backside Beck valley.

But Yarlside had its own ice. A large open combe occurs at its eastern side, with a terminal moraine below. This combe has receded by corrie-glacier erosion, cutting off the head of Little Randy Gill, a tributary of Bowderdale. The ice flowing from it, being prevented from flowing down the Backside Beck valley by the Baugh Fell ice, has flowed north-eastwards along the old beheaded Artlegarthdale, truncating the south-eastern slopes of Kensgriff, depositing drift on the col between Backside and Wandale, and carrying a train of boulders of Browgill Shales and red felsite from the upper part of Backside over the col to the Wandale Valley and onwards over the next col to Artlegarthdale. There, being prevented from going farther by the ice which had come from Wild Boar Fell by way of the north side of Harter Fell and filled the head of Ravenstonedale, the drift was dumped down.

There is one difficulty to notice. Below the hanging part of Stoneley Gill at the top of Wandale is a combe facing southwards. We would suggest that, as this lies athwart the general direction of the later ice, it may be due to a local corrie-glacier at an early stage of the Glacial Period.

We come now to the streams of the Ravenstonedale drainage, and shall follow them towards the west.

Ellergill Sike runs in a shallow valley. The stream is engaged in cutting through a deltoid mass of drift filling the valley-bottom, like those masses which occur in the gills to the north of Sedbergh and elsewhere.

North-east of Ellergill Farm is an old quarry by the high road, capped with drift and containing boulders of Carboniferous grit. In this tract of comparative lowland the general direction of the axes of the drumlins is east-north-east and west-south-west, whereas farther north-west their axes trend more nearly south-east and north-west. This points to the junction of the two ice-lobes (the one from the Lake District and the other from the Wild Boar and Baugh Fell region) in this part of the country.

The foreign drift in Gaisgill, the head of Artlegarthdale, has just been described. We may note the capture of the head waters of Wyegarthdale by this stream, with the production of the col (now occupied by drift) between Knoutsberry and The Knott on the north side of it. The former head of Wyegarthdale now forms the main tributary of Gaisgill, and enters that stream from the south immediately opposite the col. Its capture was due to the more rapid erosion of the Gaisgill stream, which runs over weak rocks along the shatter-belt. The lower part of Artlegarthdale is markedly U-shaped.

Thackthwaite Gill, west of Artlegarthdale, is a U-shaped valley with drift-filled bottom and presents no features of special interest. Wyegarthgill valley also has a deltoid mass of drift filling the valley-bottom; the head of this drift-mass lies some distance below the head of the valley.

The Dale Gill valley is wide and U-shaped, with a conchoidal scoop on its western side and a vegetation-clad combe at its head. West of this lie three very important valleys, namely Weasdale, Bowderdale, and Langdale, the last-named having also two important tributaries, Churn Gill and Uldale.

The eastern feeder of Weasdale, called Great Swindale, rises west of the top of Green Bell. The valley is V-shaped, but approximates below to the U-outline. It has a conchoidal scoop on its eastern side, with truncated spurs above and below. The bottom of the valley is occupied by alluvium nearly to the head. How far this alluvium is fluvio-glacial in origin has not been determined, though it is probable that, during the melting of the ice, the formation of alluvium in this and other valleys proceeded in a more rapid manner than has ever been the case subsequently.

At the head of Great Swindale we meet with a type of accumulation which forms a marked feature of the heads of many of the northward-flowing streams of the Howgill Fells: this requires some notice. The semicircular head of Great Swindale is occupied by loose material, which is being carved by rain-channels into buttressed ridges that are very characteristic. The general aspect of the accumulation at first sight suggests moraine, but a closer examination at once shows that it is not of morainic origin. It is composed of angular fragments of various sizes, and is clearly the result of weathering action only. Similar material occurs on the two sides of the valley some distance below the head, but is not there so thick. On the eastern side this material (continuous with that at the valley-head) covers the face of a conchoidal scoop produced by ice-erosion: hence it must be of post-Glacial origin, and cannot be due to pre-Glacial weathering. Its formation is still going on, although its destruction by occasional stream-action indicates that the formation is not now sufficiently rapid to replace the destroyed material, and the total amount is therefore dwindling: the main mass of it was probably formed by frost-action after the retreat of the ice.

The head of Weasdale proper is a large combe with similar subangular accumulation. Here the material is formed from the broken rock which fills the shatter-belt of the great fault. There is little sign of glaciation at the extreme head of the valley, the overlapping spurs of which have not been completely destroyed; but lower down the valley rapidly becomes U-shaped, and has truncated spurs. Between the points of entry of Great and Little Swindale its western side shows a good example of a well-truncated spur; and below the point of entry of Little Swindale the eastern side exhibits a similar phenomenon on the western face of High Knott. Little Swindale is largely choked by a drift-delta introduced from Dale Gill.

Little Beck, west of the lower part of Weasdale, is formed by the junction of two streams—Simongill Sike on the east, and Shawgill Sike on the west. The valley is short, and largely occupied

by drift. The head of Shawgill Sike is cut off, owing to the widening of Bowderdale by ice; and hence a marked col occurs between it and Bowderdale. Through this at one time there was a marginal overflow from the ice, and another smaller overflow drained somewhat farther north, but the water from this latter returned to Bowderdale at a lower point.

Bowderdale is the next important valley to the west. It is well graded below the col at which the capture by Cautley Gill has occurred. Below this col the valley for some distance is not appreciably glaciated, there having been no gathering-ground for the ice. About a mile north of the col it receives the waters of Hazel Gill from the west, and of Great and Little Randy Gills from the east. The valleys of these are V-shaped. Some drift occurs at the bottom of the united Randy Gill streams. Below the junction of these streams with Bowderdale the latter valley is markedly and suddenly affected by Glacial erosion, and becomes a U-shaped valley. It has a truncated spur on its eastern side between Watley and Leath Gills; and its lower part is nearly straight, with the spurs on each side of the valley well truncated. This feature is well shown by the change of slope when looking up the valley from the north side of the Lune near Ravenstonedale railway-station. We append a diagram of this, which illustrates the type of cross-section of the U-shaped valleys of the district.

Fig. 6.—*Outline of Bowderdale, seen from near Ravenstonedale railway-station.*

[The broken line indicates the pre-Glacial outline of the valley-slopes.]

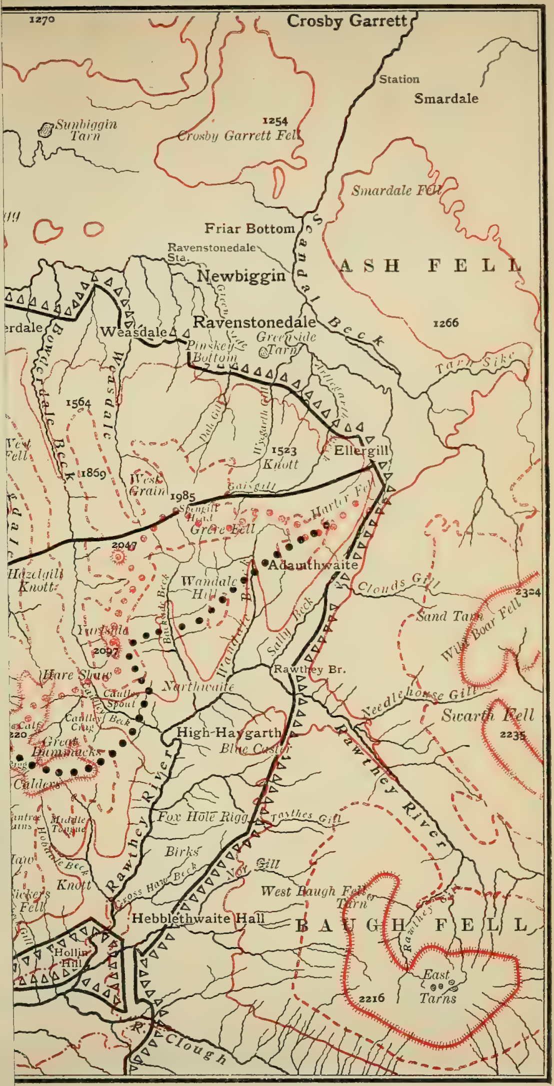
A wide expanse of moorland separates the lower part of Bowderdale from Langdale. Over this flow the two streams, Birk Gill on the east and Cote Gill Beck on the west. The tops of these valleys are cut off by the widening of Langdale by ice, and drift has passed over the cols thus produced and extends thickly down each of the valleys. Carboniferous boulders were found at Cote Gill Farm near the junction of the two streams, thus indicating that the Lake District ice occupied this more lowland region; but whether the drift at the head is that of the Lake District ice, or of ice coming over from Langdale, we did not discover.

The Langdale valley has three feeders:—Langdale Beck on the east, Churn Gill in the centre, and Uldale Gill on the west. Langdale Beck rises on the north side of The Calf, with three minor feeders of which the westernmost is beheaded by Longrigg Beck at Wind Scarth Wyke, as previously stated. The valleys

W. B. Brunskill, Photogr.

The Howgill Fells, seen from Ash Fell.

Bemrose, Collo., Derby.

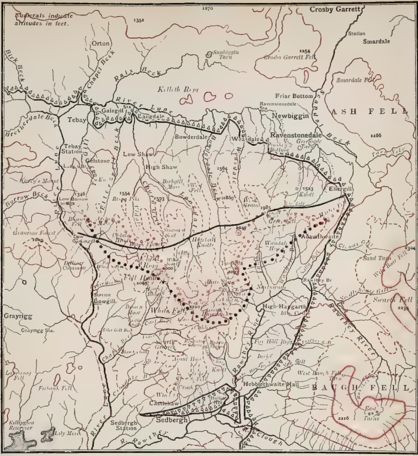


HE HOWGILL FELLS. (*Scale: 1 inch = $1\frac{1}{2}$ miles.*)

= 1500 feet; ——— = 1000 feet; — · — · — = 500 feet

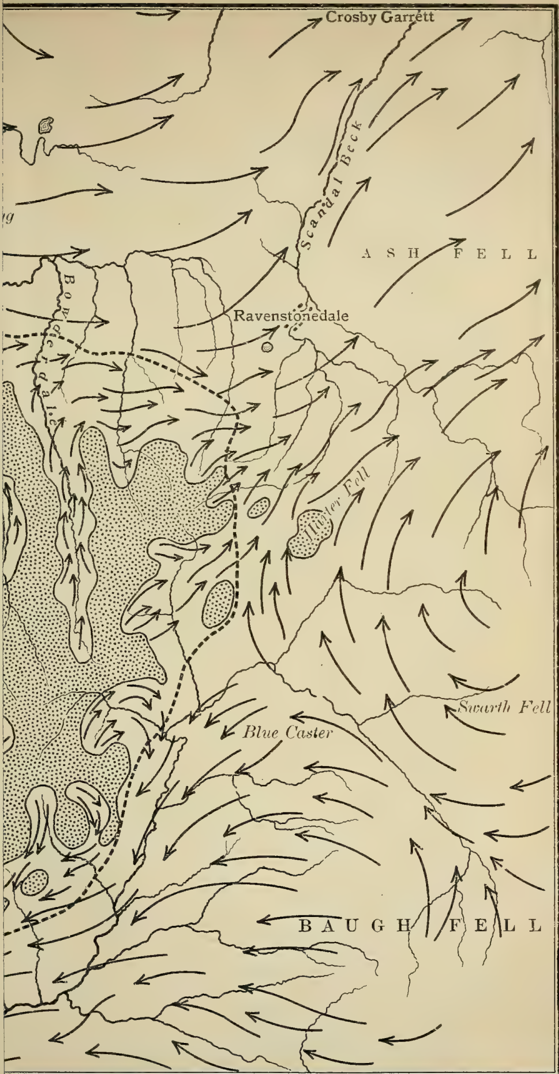
●●●●●●● = The approximate line of the watershed which separated ill area, as determined by the original uplift.

oniferous from the older strata; the triangles have been placed upon which crosses the Silurian rocks of the Howgill area.]



THE RIVERS OF THE HOWGILL FELLS. *(Scale: 1 inch = $1\frac{1}{3}$ miles.)*

[Contour-lines: ——— = 2000 feet; - - - - - - - = 1500 feet; ——— = 1000 feet; — - — - — = 500 feet
●●●●●●●● = Present watershed of the Howgill area; ●●●●●●●●● = The approximate line of the watershed which separated the northward from the southward flowing streams of the Howgill area, as determined by the original uplift
△△△△△△△△ Line of outcrop separating the Carboniferous from the older strata; the triangles have been placed upon Carboniferous rocks ——— = Line of the shatter-belt which crosses the Silurian rocks of the Howgill area]



F THE HOWGILL FELLS. (*Scale:* 1 *inch* = $1\frac{1}{2}$ *miles.*)

›ved. This has been inferred from a study of (1) the distribution of the erratic
glacial sculpture; and (3) the alignment of the drumlins and other glacial deposits.
mit to which boulders of origin external to the Howgill Fells have been observed.
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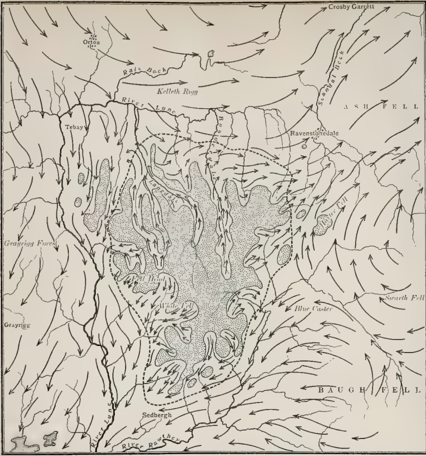
r-courses, which are the same as in the map of the rivers of the Howgill Fells (Pl. XXIX).]



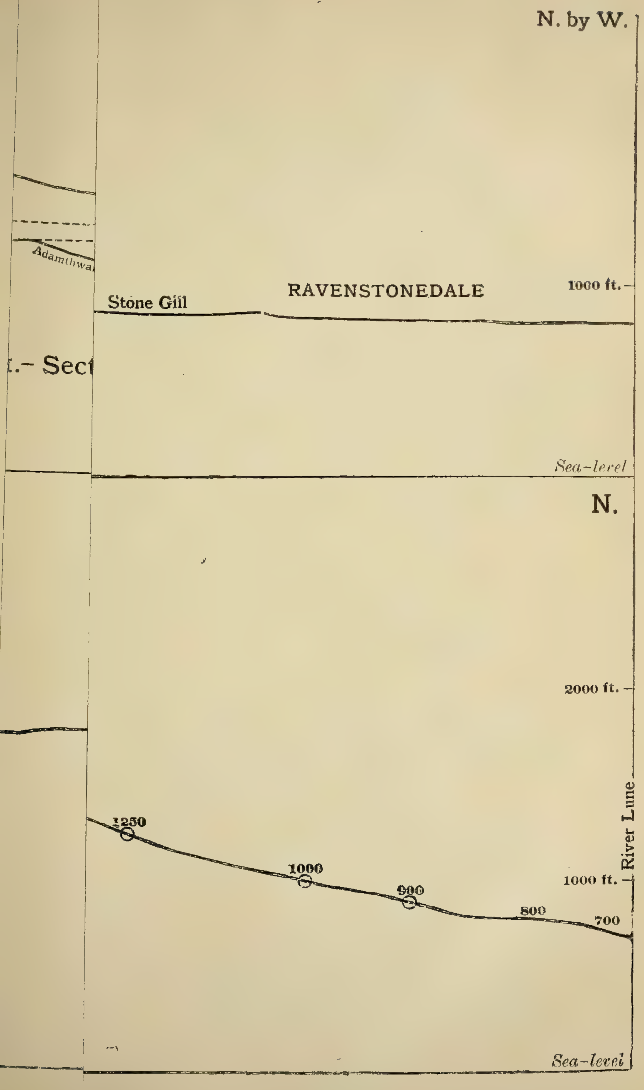
THE GLACIERS OF THE HOWGILL FELLS. *(Scale: 1 inch = $1\frac{1}{2}$ miles.)*

[The arrows mark the direction in which the ice is supposed to have moved. This has been inferred from a study of (1) the distribution of the erratic boulders; (2) the character and localization of topographic forms due to glacial sculpture; and (3) the alignment of the drumlins and other glacial deposits.

The broken line surrounding the Howgill Fell area marks the upper limit to which boulders of origin external to the Howgill Fells have been observed.

The stippling indicates the area within the Howgill district upon which no evidences of glacial sculpture or erosion have been impressed.

The topography of the district is sufficiently indicated by the lines of the river-courses, which are the same as in the map of the rivers of the Howgill Fells (Pl. XXIX).]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Sea-level

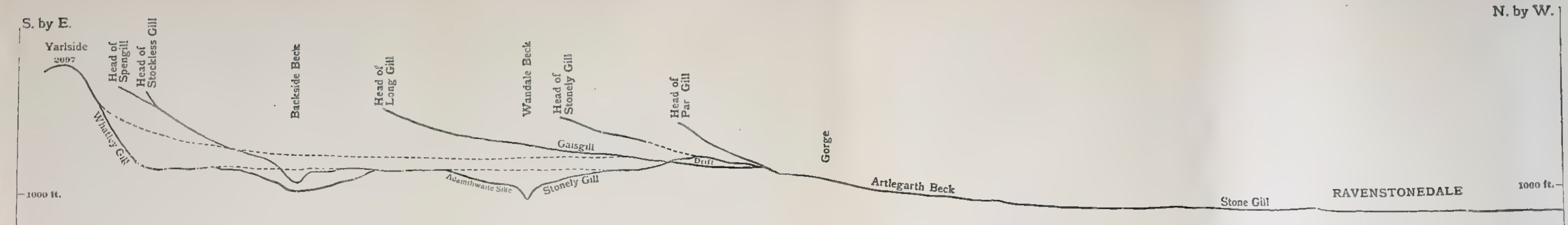


Fig. 1.– Section showing the thalweg of the beheaded Artlegarthdale and its tributary valleys.

[Scales: Vertical, 6 inches = 1 mile; horizontal, 3 inches = 1 mile.]

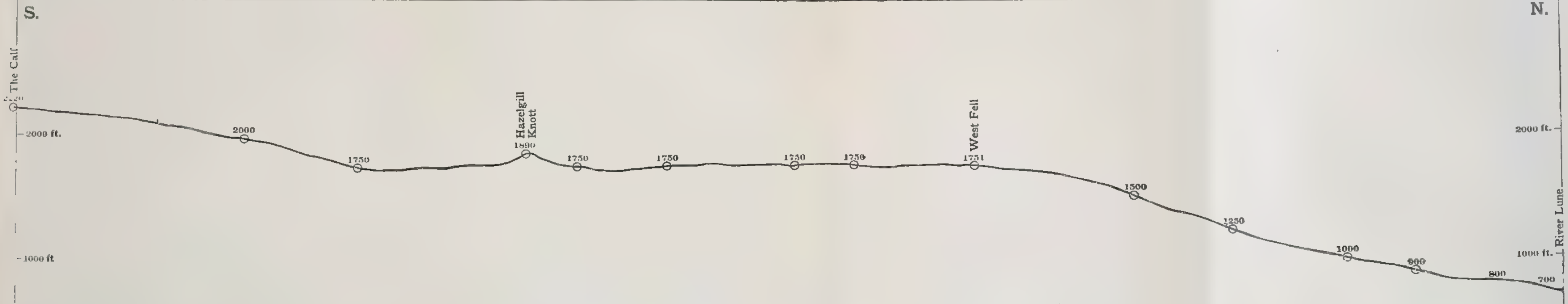


Fig. 2.– Section along the watershedding line west of Bowderdale.

[Scales: Vertical, 6 inches = 1 mile; horizontal, 3 inches = 1 mile.]

of these little tributaries have small combes at their heads; and much angular drift of the type described in Great Swindale is laid bare, and is now being cleared out from them by the stream-action. Glacial action has produced little modification of the upper part of the Langdale valley, for the valley and all its feeders above the junction of West Grain are V-shaped. The head of West Grain contains the buttressed angular drift. Below the entrance of the West Grain stream, Langdale becomes suddenly and markedly U-shaped, with conchoidal scoops in the concavities and exhibiting well-truncated spurs. The bottom is occupied by alluvium or fluvio-glacial deposit.

Churn Gill also arises in a combe with much angular material at its head. It is U-shaped, but with an approach to the V-outline lower down.

Fig. 7.—*Uldale: a typical U-shaped valley.*

The capture of the head-waters of Uldale has already been considered. North of the 'corrom' at the watershed the valley is narrow, and a small moraine lies in the bottom immediately north of Blakethwaite Bottom. It then turns due north, and north of Uldale Head there is a combe, when the valley at once becomes modified by ice-erosion, and is a well-marked U-shaped valley all the way down to its junction with the Lune.

The occupation of the two remaining valleys, Ellergill and Tebay Gill, by foreign ice has already been mentioned.

Conclusions.

We may now sum up our results by stating that the Howgill Fells are a monoclinal block, formed of Silurian rocks which have been glaciated by their own ice. The erosive effects of the ice have been chiefly exerted in widening the valleys, by truncating the spurs and forming conchoidal scoops on the concave sides. The amount of deepening is small, as indicated by the slight difference of grade at the junctions of the tributaries and the main streams which is measured by only a few or at the most by tens of feet, the latter in the case of the junctions of the streams on the west side of the Fells with the River Lune. Accordingly, the hanging of the tributaries is insignificant. The great hanging valleys have been determined by the capture of the head-waters of the northward-flowing streams by the more steeply graded streams flowing southwards or south-westwards, although these captures have been partly aided by glacial action.

The rarity of roches moutonnées and ice-scratched surfaces is a noticeable feature, but it must be remembered that the places favourable for their preservation are chiefly masked by vegetation.

The comparatively feeble action of the ice may, of course, be largely due to its inability to obtain free outlet from the Fell country, owing to resistance and interference of the Lake District ice on the one hand and of the Wild Boar Fell and Baugh Fell ice on the other; and we have no desire to generalize, as to the action of ice in other regions, from our observations in this limited tract. We think, however, that our work may prove useful, as showing the varied effects of glaciation in a district of practically homogeneous rock, where there is every gradation from the ordinary valley-outlines of a water-eroded tract of moel type to those of a marked U-shape, such as are seen at Cautley where ice has exerted a very considerable influence.

EXPLANATION OF PLATES XXVIII-XXXI.

Plate XXVIII.

The Howgill Fells, seen from Ash Fell. The cultivated valley in the middle distance is Ravenstonedale. Notice the gentle northerly slope, increasing in steepness as it approaches the valley (see also Pl. XXXI, fig. 2) and the steep scarp facing southwards.

Plate XXIX.

Map of the rivers of the Howgill Fells, on the scale of a mile and a half to the inch.

Plate XXX.

Map of the glaciers of the Howgill Fells, on the scale of a mile and a half to the inch.

Plate XXXI.

Fig. 1. Section showing the thalweg of the beheaded Artlegarthdale and its tributary valleys.

2. Section along the watershedding line west of Bowderdale.

[Scales: vertical, 6 inches = 1 mile; horizontal, 3 inches = 1 mile.]

32. *The* Cauldron-Subsidence *of* Glen Coe, *and the* Associated Igneous Phenomena.[1]

By Charles Thomas Clough, M.A., F.G.S., Herbert Brantwood Maufe, B.A., F.G.S., and Edward Battersby Bailey, B.A., F.G.S. (Read May 26th, 1909.)

[Plates XXXII–XXXIV.]

Contents.

I. Introduction.

During Lower Old Red Sandstone times the district of Glen Coe furnished an arena wherein terrestrial disturbance and igneous activity combined to produce effects of imposing magnitude and, as we believe, of some theoretical importance. The paper now presented embodies an account of a cauldron-subsidence which affected an area roughly oval in shape, and measuring not less than 5 miles from side to side. We show that the subsidence took place in at least two stages, and that it was accompanied in a complementary fashion by the uprise of a series of marginal intrusions.

In the first instance the nature of the volcanic succession in Glen Coe will be dealt with, its variations from point to point will be described, and evidence will be adduced to illustrate the marked inequalities of the floor of Highland Schists upon which these volcanic rocks accumulated. The second portion of the paper is devoted to the evidences of the cauldron-subsidence, and treats in some detail of its tectonic features and the accompanying plutonic

[1] Communicated by permission of the Director of H.M. Geological Survey.

intrusions. In a final section we hav added a theoretical discussion of our results.

Situated between Oban and Fort William, in the midst of the mountainous region of Northern Argyllshire, the district of Glen Coe affords a series of magnificent natural sections. The Pass, even at its summit, barely reaches the 1000-foot contour, while the majority of the hills on either side rise steeply to altitudes of 3000 feet and more. Bidean nam Bian, the highest mountain in Argyllshire, attains the elevation of 3766 feet, and the average gradient of its flanks, measured from the valley-floor, amounts to 25°. Individual slopes are, of course, much steeper than this; the face of Aonach Dubh, above Loch Achtriochtan, for example, is an all but inaccessible cliff, rising 2000 feet at an angle of 55°. In addition to this, the comparatively recent glaciation of the district has left the rock-surfaces fresh and clean, and the covering of morainic drift is everywhere remarkably light.

But want of railway connexion, which has only recently been established, and the physical impossibility of dealing with such hills in a limited space of time, have proved obstacles in the way of scientific research, and Glen Coe has never received so much geological investigation as it deserves.

Among the older geologists, MacCulloch,[1] Macknight,[2] Boué,[3] and Nicol[4] have given brief accounts of their visits to the Glen. They recognized the existence of crystalline schists and gneisses, granite or syenite, dykes of 'felspar-porphyry,' and masses of 'compact felspar' and 'hornstone,' but the complex relations of these rock-masses were scarcely, if at all, understood.

In 1874 Prof. Judd included a short description of Glen Coe in his account of the Newer Palæozoic Volcanoes of the Western Highlands.[5] He recognized a great series of 'felstone' lavas, underlain partly by schists and partly by granite, and remarked on the close similarity in petrological characters between the Glen Coe lavas and those which make up larger areas in Lorne and the Ochil and Cheviot Hills. He also called attention again to the multitude of dykes traversing schists, granites, and lavas alike.

In 1900 Mr. H. Kynaston began work in the district on behalf of the Scottish Geological Survey. He received assistance from Dr. B. N. Peach, who was at that time in charge of the West Highland division, and in 1902 a joint excursion was undertaken by Dr. Peach, Mr. Kynaston, and Mr. Tait, primarily with the object of establishing the age of the Glen Coe volcanic group. This expedition was entirely successful, for Mr. Tait obtained remains of two Lower Old

[1] 'Observations on the Mountain Cruachan in Argyllshire, with some Remarks on the Surrounding Country' Trans. Geol. Soc. vol. iv (1817) p. 132.

[2] 'On the Mineralogy & Local Scenery of certain Districts in the Highlands of Scotland' Mem. Wernerian Nat. Hist. Soc. vol. i (1811) pp. 311–18.

[3] 'Essai géologique sur l'Écosse' Paris, n. d. p. 67.

[4] 'Guide to the Geology of Scotland' Edinburgh, 1844, pp. 159–61.

[5] Quart. Journ. Geol. Soc. vol. xxx (1874) p. 220.

Red Sandstone plants, determined by Dr. Kidston as *Psilophyton* and *Pachytheca* respectively, from a bed of black shale underlying the lavas on the northern face of Stob Dearg. Specimens of *Psilophyton* were also found in dark-grey shales and mudstones underlying the basic andesites on the north side of Glen Coe above Loch Achtriochtan.[1]

Mr. Kynaston published brief summaries of his researches as they proceeded[2]; but his final, and in some instances modified, conclusions can only be found in the manuscript notes left by him on his departure for South Africa in 1903. In many directions little advance has been made from the position indicated in these notes. Thus Mr. Kynaston describes in detail the volcanic succession developed in Aonach Dubh and Bidean nam Bian, which, as will be seen later, provides a typical section of the area. He also gives an account of the interesting boulders of granite, andesite, and quartz-porphyry in the basement conglomerate exposed on the hillside north of Loch Achtriochtan. Further, he accounted for the position of the rhyolites of Stob Dearg, or rather the absence of the Aonach Dubh andesites beneath them, by assuming an overlap of the rhyolites eastwards against an uneven floor of schists. And he even interpreted the vertical junction of the volcanic rocks with the schists in the Cam Glen as an extreme example of this unevenness. Here again we have followed Mr. Kynaston, after a careful consideration of all the evidence in the field.

He also demonstrated that the Ben Cruachan granite is later than the Old Red volcanic rocks, since it invades and alters them; and finally we may record that in An t-Sron, above Loch Achtriochtan, he had begun mapping the boundary-fault of the Glen Coe cauldron. He had, in fact, realized, so far as was possible from a single section, the fundamental relation subsisting between this fault and the intrusive rock which so constantly accompanies it. We may illustrate this point by quoting his manuscript:—

> 'On the south side of Glen Coe, south-south-west of Loch Achtriochtan, a well-marked line of fault, indicated by a deep cleft on the north-east slopes of An t-Sron, cuts off abruptly the basic andesites which are seen on the east side. On the west side occurs a mass of granite which shows a marginal facies along the line of the fault, so that it is possible that the fault may be older than the granite.'

Our own connexion with the district dates from the years 1903 and 1904.[3] During 1903 Dr. Peach was still in charge, and did some mapping in the area himself. The time during which he was actually at work in the district was very brief, but the value of his influence will never be forgotten by those whom he introduced to the varied geological problems of Glen Coe.

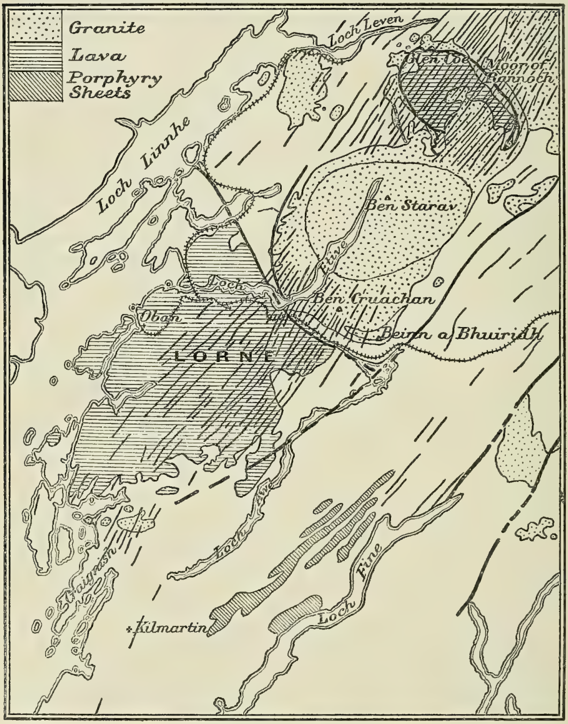
[1] 'Summary of Progress of the Geological Survey for 1902' (1903) pp. 79 & 130.

[2] *Ibid.* 1900 (1901) pp. 75–85; 1901 (1902) pp. 137–40; and 1902 (1903) pp. 78, 79, & 130.

[3] *Cf.* 'Summaries of Progress of the Geological Survey', especially those for 1904 (1905) pp. 67–69, and for 1905 (1906) pp. 95–99.

From 1904 to 1906 Mr. G. W. Grabham was working alongside of us. Before leaving for the Sudân, he had completed Mr. Kynaston's mapping of the Buachaille Etive Mor and adjoining areas. He had also traced the fault bounding the Glen Coe subsidence from the

Fig. 1.—*Sketch-map of the volcanic district of Northern Argyllshire, showing the distribution of dykes in relation to the Etive granite complex.*



[Scale: 10 miles = 1 inch.]

The Highland Schists are left white. Faults are shown by heavy black lines.

Coupall River to the Cam Ghleann. But, perhaps, the chief feature of his work was the establishment of the early age of the great Moor of Rannoch granite, by showing that it was invaded by the intrusion accompanying the Glen Coe fault.

II. The Glen Coe Volcanic Series.

(a) Type Section.

The Coire nam Beith section, south of Loch Achtriochtan (Pl. XXXII & Pl. XXXIII, Sections II & IV) furnishes the best introduction to the study of the volcanic series of Glen Coe, including, as it does, an excellent exposure of the base of the group resting upon the Highland Schists. After gaining the head of the valley, Bidean nam Bian should be ascended and the traverse continued to the southern summit of Beinn Fhada, in order to reach the youngest volcanic rocks preserved anywhere in the district. The full sequence thus encountered may be stated as follows:—

		Thickness in feet.
7. Andesites and rhyolites	about	300
6. Shales and grits		50
5. Rhyolite		250
4. Hornblende-andesites		900
3. Agglomerates and shales		250
2. Rhyolites (and andesites elsewhere)		450
1. Augite-andesites		1500
Total		3700

(1) Augite-andesites.—The junction of the augite-andesites of group (1) with the underlying schists is well exposed in the course of the stream. Some 2 feet of purple sandy shale, with slivers of phyllite, occur beneath the bottom lava. There are in all about seventeen flows of augite-andesite in this section, and their bedded nature is well shown on the face of Aonach Dubh.

Like the majority of the lavas of Glen Coe, they are vesicular only in a minor degree. Their contemporaneous nature can, in fact, best be inferred from the occasional intercalation between them of beds of shale. In some cases, too, they have become brecciated, through and through, during the process of cooling, and the interstices subsequently filled in with thin seams of horizontally bedded shale. Breccias of this type are especially well seen near the summit of the group in Coire nam Beith. They can be distinguished from agglomerates, since each fragment possesses identical lithological character, and its boundaries frequently conform accurately to the irregularities in neighbouring blocks. The breccias are also quite different from the brecciated lavas so common among the rhyolites to be described later, where brecciation and inclusion of xenoliths occurred long before movement in mass had ceased.

The upper surfaces of some of the andesitic lavas are reddened in a manner which at once suggests contemporaneous weathering. Petrographically, too, these rocks are typical lavas, with a fine-grained ground-mass exhibiting flow-structure, and including small phenocrysts of augite, often accompanied by pseudomorphs of iddingsite after olivine.

(2) Rhyolites.—The augite-andesites are succeeded towards the head of the corrie by three rhyolite flows. Each of these lavas is about 150 feet thick. It is usually found in Glen Coe that the more acid, and presumably more viscous, rocks give rise to the thicker lava flows of the series. They also furnish bolder and more massive crags than their associates, and the three now under consideration can on this account be readily recognized, even from the road. Flow-banding is generally conspicuous in these lavas, and the uppermost shows flow-brecciation also.

(3) Agglomerates.—The next group in the sequence consists of a mass of agglomerate underlain by about 20 feet of greenish sandy shale. The agglomerate is made up of blocks of augite-andesite and rhyolite, of all sizes up to a foot in length.

(4) Hornblende-andesites.—The hornblende-andesites of Bidean nam Bian, which seem to consist of a series of flows, are readily distinguished from the augite-andesites of group (1). They carry numerous small, but conspicuous, phenocrysts of plagioclase in addition to prisms of hornblende. They are more acid in character than the augite-andesites, and frequently show flow-banding, which is conspicuous on the weathered crusts. They occasionally exhibit a hexagonal columnar jointing due to cooling.

(5) Rhyolite.—The rhyolite which succeeds the hornblende-andesites on Beinn Fhada is not divisible, and may, indeed, be a single flow. On a fresh fracture the rock is black and vitreous, rich in phenocrysts of felspar, but poor in respect of quartz. Its main characteristic is the prevalence of the brecciated structure already noticed in the case of the uppermost lava of group (2). Numerous fragments of rhyolite and hornblende-andesite, together with occasional pieces of quartzose schist, are included as xenoliths in a matrix which shows clear signs of flow-banding.

(6) Shales and grits, well stratified and greenish grey in colour, now interrupt the succession of volcanic rocks. Lying upon the irregular surface of the rhyolite, they are naturally variable in thickness, and point to the deposition of volcanic detritus in a local body of water. Their varying angles of dip form an important index to the deformation which the rocks have undergone since their deposition (Pl. XXXIII, Section III).

(7) Andesites and rhyolites.—The group of lavas succeeding the sediments consists of rhyolites, hornblende-andesites, and one basic andesite, and serves as a striking example of irregular accumulation. The older members are found only in the south-east, on the hill above Dalness, while the later members overlap the older in such a way that the youngest lava preserved to us rests on the sediments of group (6), and caps the southern summit of Beinn Fhada. It is a hornblende-andesite characterized by an abundance of relatively large plagioclase phenocrysts, a feature which gives it a superficial resemblance to certain dykes of hornblende-porphyrite.

(*b*) General Distribution and Variation of the Volcanic Series.

Employing the Coire nam Beith section as a standard, we may now attempt to give in outline an account of the rapid local variations which are characteristic of the volcanic sequence of Glen Coe. To approach this subject in the simplest manner, the usual method of procedure must be reversed and the succession described from above downwards.

The andesites, rhyolites, and sediments of groups (7) and (6) may be dismissed at once, since, having escaped erosion merely on the southern shoulder of Beinn Fhada, their description has already been included in that of the type section.

The rhyolite of group (5) occupies much of Beinn Fhada, and also forms an outlier upon the Buachaille Etive Beag. It is likely, too, that it enters into the composition of the contact-altered rhyolitic mass forming the southern end of the Buachaille Etive Mor. It is everywhere prone to display the brecciated and xenolithic character described in the type section. Its base-line is characterized by an irregular, but moderately high, southerly inclination (Pl. XXXIII, Section III).

The constancy of the hornblende-andesites of group (4) is of the greatest assistance in the task of piecing together the volcanic sequence of Glen Coe. The outcrop of the group is continuous from Stob Coire nan Lochan to the Buachaille Etive Beag, while an outlier forms the median summit of the Buachaille Etive Mor, and flat cakes cap the hill-tops on the two sides of the Cam Ghleann (Pl. XXXIII, Section I).

The mass of agglomerate, group (3), coming immediately beneath the hornblende-andesites in Stob Coire nan Lochan, marks an important period during which few, if any, lavaform eruptions occurred. It is possible, indeed, that the deposit is mainly detrital in nature, and not, strictly speaking, a volcanic agglomerate at all. The accumulation is inconstant in character: for, when traced into the eastern slope of Stob Coire nan Lochan, it becomes finer in texture, while hard green siliceous shales make their appearance in the upper portion of the group, and shortly swell to a thickness of 100 feet. The shales with bands of grit can be traced along the western slope of Beinn Fhada, but are here much diminished in thickness.

For some distance along the eastern slope of Beinn Fhada, the shales are lost sight of; but, reappearing once more near the head of the Lairig Eilde, they can be followed north-eastwards into a thick mass of agglomerate in the Buachaille Etive Beag similar to

that in the type section. This agglomerate forms an isolated outcrop on the Buachaille Etive Mor, where it is once more found to be inconstant in a southerly direction.

Farther south-eastwards, across Glen Etive, the deposit is very strongly developed, and extends from Sron na Creise, round the head of the Cam Ghleann into Meall a' Bhuiridh. In the latter hill it comes into direct unfaulted contact with the Highland Schists, thus indicating a very remarkable overlap. The greater part of its mass is here a mixed breccia of schist and rhyolite fragments, but the upper portion near the overlying andesites also contains numerous andesitic fragments.

Returning to the type section on Bidean nam Bian, it is found that the agglomerate cannot be traced far to the south-east, and the position of the group has not been detected in the neighbourhood of Dalness.

The abundant well-bedded rocks in group (3) give much assistance in working out the structure of the district. It is found that the sediments and lavas of the central portion of the Glen Coe cauldron dip in a southerly direction, sometimes at low and sometimes at rather high angles. This structure can only be detected away from the margins of the subsidence: for, in the proximity of the boundary-fault, the dominant characteristic is a steep upturning of the various subdivisions, occasionally leading to actual inversion (Pl. XXXIII, Section IV).

The local variations of group (2), represented by rhyolites alone in the type section, are extremely interesting. Traced into the western peak of Bidean nam Bian, where the rocks stand on end in proximity to the boundary-fault (Pl. XXXII), the rhyolites die out entirely. Followed to the east, on the other hand, through the 'Three Sisters of Glen Coe' (Aonach Dubh, Gearr Aonach, and Beinn Fhada), the group expands, and in the last of the three, Beinn Fhada, and also in the opposite slopes of the Buachaille Etive Beag, it includes a very large proportion of andesitic flows. Among these latter both augite- and hornblende-andesites occur, and their intercalation with the rhyolites, which they more or less replace in the succession, can clearly be traced in Beinn Fhada. The thickness of the group in this locality must be about 2000 feet (Pl. XXXIII, Sections I, II, & III).

Farther east again, the andesite lavas of group (2) disappear even more suddenly than they came. Not one of them extends round the northern face of the Buachaille Etive Beag, for this consists entirely of rhyolite. This rhyolitic development, locally interrupted by the important agglomerate of Lochan na Fola, continues south-eastwards into the Buachaille Etive Mor (Pl. XXXIII, Section II), and across the River Etive into the Cam Ghleann; on the northern face of Glen Coe, however, andesites greatly predominate, and group (2) is represented in much the same manner as in some parts of Beinn Fhada to the south.

The main structural features of this north-eastern portion of the district are readily understood. Sharp marginal upturning exposes the base of the group, resting, with the intervention of a variable accumulation of breccia, sandstone, and shale, upon the old schist floor. The base is seen in Coire Mhorair and Coire Odhar-mhor, and then may be followed fairly continuously towards the south-east across Glen Coe and Glen Etive into Sron na Creise. The average dip along this line is probably not less than 50°, while the beds are sometimes vertical or, as in Coire Mhorair, overturned (Pl. XXXIII, Sections III & IV). This marginal dip towards the south-west meets the south-easterly marginal dip, which prevails in the western half of Glen Coe, and thus gives rise to a shallow synclinal structure, the centre of which is marked by the outcrop of andesite crossing the River Coe at the foot of the Buachaille Etive Beag.

In the Cam Ghleann, strangely enough, the rhyolites flatten, and in the river-bed are found resting upon a seam of dark shale, which in turn overlies a massive flow of augite-andesite. Probably this latter is a representative of the augite-andesites of group (1). Between it and the schists a conglomerate, exposed in the river, contains blocks of schist and many boulders of granite.

To the south, in the Dalness district, group (2) is apparently represented by interbedded rhyolites and andesites in the Lairig Gartain; and by a rhyolitic group, including probably both lavas and agglomerates, on the slopes of Beinn Ceitlein, south of Glen Etive. In the latter locality a variable intercalation of ashes and ashy sandstones immediately underlies the rhyolites, and, in places, exceeds 200 feet in thickness, but is very lenticular.

The basic andesites of group (1), which figure so prominently in the Coire nam Beith section, cross Glen Coe, and their unconformable junction with the schists is well displayed on the slopes north-west of Loch Achtriochtan. The basement beds are here very different from the sandy shales, 2 feet thick, which occur in like position in the type section, for they consist chiefly of conglomerates containing well-rounded boulders of granite, andesite, and schist. The andesitic boulders and pebbles include both the augitic and hornblendic types found among the overlying volcanic rocks. A few quartz-porphyry pebbles can be found, but other dyke rocks appear to be wanting. The granite boulders exactly resemble those found in the basement conglomerate of the Cam Ghleann. With its associated sandstones and shales, the conglomerate series above Loch Achtriochtan is about 60 feet thick. It is seen again, with like characters, in Coire Cam at the foot of Meall Dearg, where it is overturned at an angle of 70° in close proximity to the fault.

The andesites overlying the conglomerate in the slopes of Aonach Eagach are the continuation of those already described in Coire nam Beith. The upper limit of the group is, however, very ill-defined on this side of Glen Coe, owing to the change of character in the succeeding division (Pl. XXXIII, Section IV). There is a

further exposure of the base of the group in the stream-bed of Coire nan Lab, but the conglomerate is absent here, and the sedimentary beds consist mostly of shale.

Southward group (1) may be traced in strong development along the slopes of Bidean nam Bian to Dalness, where at several points in the bed of the Etive and in the adjoining slopes, the old schist floor shows through, in a highly irregular manner. These inliers of the Highland Schists are often in a disturbed and brecciated condition for a thickness of a few feet down from the surface. In other cases they are massive throughout, but sprinkled over with a few angular scraps and fragments of rock.

Reference may again be made to the basic andesite, resting upon conglomerate containing granite boulders, which lies at the base of the volcanic pile in the Cam Ghleann. It is quite probable that this represents an original extension of group (1) in an easterly direction.

(*c*) The Uneven Floor upon which the Volcanic Series reposes.

In the preceding section evidence has been adduced of an unconformable overlap in the volcanic series of such a character that, in an easterly direction, beds of group (2) and even of group (3) come to rest directly upon the old schist floor. The absence of group (1) may merely indicate that the source of supply in this instance lay to the south-west, but that of group (2) between Cam Ghleann and Allt Coire an Easain can be definitely correlated with the very irregular form of the old floor.

In ascending the Cam Ghleann from the position of the boundary-fault, we encounter several detached outcrops of rhyolite and andesite, and also patches of breccia, consisting of angular fragments of schist and rhyolite. The relations of all these rocks to the surrounding schists strongly suggest that they accumulated on an extremely irregular surface, but the most striking example of such an irregular pre-existing surface is exposed farther up the glen. In this direction the main mass of the rhyolite lavas is encountered underlain, as already described, by several feet of shale, below which comes a thick dark andesite resting on a conglomerate containing granite boulders. The dip, which is steep in Sron na Creise, on the west, is here very low, and yet the boundary between the volcanic rocks and the schists runs as if it were the trace of a vertical plane, straight up the hill-slope to the east. The exact junction between the two groups of rocks is not clearly seen on this hill-face; but patches of breccia accompany the schists in proximity to exposures of rhyolite, and, once on the hilltop, it is possible to demonstrate that the boundary is not a faulted one. Here the agglomerate, group (3), overlying the rhyolite, group (2), is reached; and at one locality a particular bed can be traced some little distance in advance of the main volcanic mass, and can be shown to repose as

a more or less flat cake upon the quartzose schists. Elsewhere patches of rhyolite lava occur near the margin of the group, and here and there the base of one or other of these flows can be seen filling numerous minor inequalities of the old surface of the Highland Schists. It is evident, therefore, that group (3) has, in this case, overlapped on to a steep slope, perhaps even a cliff, of the original topography of Old Red Sandstone time (Pl. XXXIII, Section I).

In Allt Coire an Easain the base of the same group (3), consisting here mainly of breccia derived from the Schists, is again exposed in a manner which brings vividly to mind the extreme unevenness of the old eroded floor. The breccia is frequently absent from slopes precisely where it might be expected to occur, while it crops up in many an odd situation where its presence could never have been anticipated. It is even found tucked away beneath projecting ledges, or packed into holes which represent ancient caves. The picture of a rough land-surface smothered beneath accumulating débris is in fact complete.

An insight into the irregularities of the old topography is also furnished in Glen Etive, a little above Dalness. On the south side of the river several exposures of siliceous schist are found not much above the level of the stream; while, some 400 yards away to the north, a small patch of similar schist is again seen about 300 feet higher. Close by this patch is a band of breccia, shown upon the map. This bed consists of fragments of siliceous schist, and can be traced for some distance at a level a little below the lowest of the rhyolite lavas of group (2).

In contrast with the sections described above, the old floor upon which the volcanic rocks rest at the western end of Glen Coe is relatively smooth and regular (Pl. XXXIII), a circumstance which is doubtless due to the fact that it is composed of uniform and relatively soft phyllites, in contradistinction to the harder quartzose schists or mixed quartzites and phyllites forming the ancient surface in the Cam Ghleann and again around Dalness.

Reference may now be made to some small patches of breccia, which have been observed lying on an uneven surface of the Highland Schists, outside the fault bounding the volcanic rocks. The largest of these patches rests against a steep slope of quartzite, at a height of 2,500 to 3,000 feet on Sgor nam Fiannaidh, and consists of quartzite fragments, together with small pieces of red felsite and porphyritic andesite, set in a siliceous matrix. Another smaller accumulation is preserved in a deep hollow of the phyllites at the head of Gleann Chàrnan, and is made up of large subangular blocks of phyllite, mixed with a few small fragments of quartzite. Both these breccias are pierced by the 'fault-intrusion,' or by an apophysis from it, and are also cut by later porphyrite dykes. They are, therefore, similar in constitution and in geological relations to the basement breccias already described; and accordingly they may be regarded as outlying portions of the same, gathered upon the highly uneven land-surface of the period.

The examples so far chosen to illustrate the irregular nature of the old land-surface do not demand any special explanation. There are other cases, however, where it is exceedingly difficult to reconcile the observed facts with the simple conception of a normal erosion-topography. At the same time it must not be forgotten that landslip-cracks are a prominent feature in the topography of some parts of the Highlands of to-day. More especially is this true of districts formed of phyllitic rocks, or of phyllites and quartzites folded together, such as constituted the buried topography of Glen Coe. Landslip-cracks filled with débris and lava are well calculated to present difficulties of interpretation when brought to light in so involved a district as the one under consideration. But, from what is known of active modern volcanoes, it is unnecessary, and even unwise, to assume that all the irregularities which can be detected are the work of erosion aided and abetted by gravitation alone. We cannot suppose that Glen Coe was exempt from the shaking and shattering by earthquake-violence which constitute such disastrous accompaniments of recent volcanic activity. Possibly, therefore, some of the deposits of the district were accumulated in open fissures or g j a s, produced during the period of vulcanicity. Such gjas are well known at the present time in the desert regions of Iceland.

An example which is considered suggestive in this connexion will now be described. The north-eastern margin of the volcanic rocks, as may be seen from the map, descends the northern slopes of the valley of Glen Coe and, crossing the Coupall River, mounts some little way up Stob Dearg without perceptibly altering its course. The straightness of the boundary is in this case due to the steep south-westerly inclination of the rocks, which dip at angles often amounting to 50° and more towards the south-west, as has already been described. This structural feature may be especially well discerned on the western face of Stob Dearg, where the Lochan na Fola agglomerate with its associated shale bands is inclined at very high angles, and is sometimes even vertical. One would scarcely expect, under the circumstances, to see anything more of the volcanic rocks between this tilted margin and the great boundary-fault to the north, which is held responsible for the disturbance. But, as a matter of fact, there is a belt, extending from the Devil's Staircase to Glen Etive (perhaps even including some of the isolated outcrops in the Cam Ghleann) along which exposures of rhyolite and breccia are constantly making their appearance. The belt along much of its course passes through ground which is obscured by superficial deposits, so that often its existence can only be recognized in isolated stream-sections. It lies between half and three-quarters of a mile in front of the main volcanic outcrop, and it runs for the most part through lower ground than is traversed by the base of the latter. Careful examination of that part which crosses the face of Stob Beinn a' Chrùlaiste, above Altnafeadh (fig. 6, p. 648), shows that the rhyolite outcrops, which it includes, consist of irregular patches, often separated from the

adjacent Schists by thin breccias, and therefore allied in their behaviour to the lavas of the district rather than to the intrusions. The breccias here consist of small angular fragments of schists; in the Coupall River, along the same line, pieces of rhyolite are also common.

Although occasionally resting directly upon the Schists, the lavas of Glen Coe are more commonly separated from the older rocks by lenticular masses of sediment, examples of which have already been mentioned. In addition to red and green shales and grits, these sediments include several varieties of coarse breccia and conglomerate. In some cases the breccia is merely a thin layer of shattered fragments of the subjacent rock into which it passes imperceptibly, and from which it has been derived by simple weathering without transportation. In other cases, peaks and ridges of quartzite and quartzose schist have showered down their débris in long trains of scree, to be met and covered by the advancing lavas. Occasionally, too, mingling with the angular local blocks are found rounded boulders from a distant source, as if ephemeral torrents had assisted in the transportation. Of such a mixed character is the basement conglomerate in Gleann Fhaolain, on the southern flank of Bidean nam Bian. Lenticular masses of conglomerate also are occasionally met with, as on Aonach Eagach. They consist of well-rolled, rudely spherical boulders of a great variety of rocks, the majority of which have been brought from a distance. The boulders are packed into a gritty matrix, and the whole deposit resembles nothing so much as the boulder-gravel in the bed of a torrent.

In addition to the basement beds, recurrent sheets of shale and grit were spread out between successive flows, while screes trailed down from neighbouring crags. The finer sediments, like the coarser deposits, are marked by rapid variations in thickness, and only in a few cases are they traceable for any distance. They may have been deposited in lakes, temporarily occupying the floor of the cauldron; or perhaps, they were laid down merely in pools and back-waters by streams which washed over the surface of the fissured lava flows, and filled every crack and crevice with soft and penetrating silt. With these considerations in mind, there can be little hesitation in believing that the eruptions in Glen Coe took place under subaërial conditions.

(*d*) Summary of the Volcanic History.

(1) The Glen Coe volcanic rocks are of Lower Old Red Sandstone age, as is indicated by the plants, *Psilophyton* and *Pachytheca*, found by Mr. Tait in the basement beds on Stob Dearg and Aonach Eagach.

(2) Three main types of lava are represented, namely, augite-andesite, hornblende-andesite, and rhyolite. There is no evidence

of an orderly sequence in the eruptions. The constitution of the pile of lavas seems to indicate that the district was supplied from more than one centre, under such conditions that individual foci were independent of one another in regard to the type of material erupted, even though their periods of activity overlapped to a very considerable extent. On this hypothesis alone it seems possible to understand the variations of group 2 (p. 618).

(3) The great rarity of pumiceous varieties of lava, and the correlative absence of tuffs possessing typical ash-structure, lead to the conclusion that the eruptions were not as a rule accompanied by explosion, but belonged rather to the quietly welling, effusive type. Such fragmental rocks as may have a pyroclastic origin form but a small fraction of the volcanic succession, and are of a kind not easily distinguished from the true sedimentary rocks with which they are associated.

(4) The volcanic rocks accumulated on a denuded and irregular land-surface of the Highland Schists, which was relatively smooth where formed of easily disintegrated phyllites, but carved into crag and ravine where constituted of the more resistant quartzites and quartzose schists. The deposits commonly intervening between the lavas and the old floor comprise breccias formed of the shattered local rock, angular scree-like breccias, and also boulder-conglomerates such as may have been accumulated by torrents.

Thin lenticular beds of shale and grit and coarse breccias recur at intervals between the lavas, some of which have their cracks and crevices filled up by horizontally bedded silt. Such deposits point to the presence of streams, and probably also of temporary lakes occupying the floor of the cauldron. From a consideration of the whole evidence it is thought that the eruptions were subaërial. The suggestion is made that some anomalously situated breccias and patches of lava may be due to the infilling of landslip-cracks and earthquake-rents.

(5) Away from the faulted margin of the subsidence, the volcanic rocks possess a general, but variable dip in a southerly direction.

III. The Boundary-Fault and the Fault-Intrusions.

(*a*) General Description.

In view of the important theoretical issues involved in the interpretation of the cauldron-subsidence of Glen Coe and its attendant igneous phenomena, detailed descriptions are necessary to show the nature of the evidence which is encountered from point to point along the course of the boundary-fault. Before entering upon a piecemeal consideration of this evidence, however, a general description of the more important features has been compiled under several headings, without regard to geographical arrangement. In the next section local details will be considered in the order in which they present themselves to anyone following the circuit of the fault, but repetition will be avoided so far as is possible.

(1) Distribution of the Volcanic Series in relation to the faulting.—The Volcanic Group of Glen Coe occupies a compact area with a simple outline, as shown on the general map (Pl. XXXIV). In many cases the lavas abut against the steep even plane of the bounding fault, and there stop abruptly. Such a relation is especially well seen between An t-Sron and Dalness (Pl. XXXIII, Sections II & IV).

There is usually also a marginal inward tilt of the volcanic rocks, which is evidently the result of the subsidence, and more or less clearly determined by proximity to the fault-line; the strike of the tilted rocks is everywhere in close agreement with that of the fault in the immediate vicinity.

This marginal tilting, to which reference has been made more than once in the preceding descriptions, is most conspicuously exhibited in the western portion of Bidean nam Bian. Here the volcanic rocks, with one or two thin intercalations of shale, are thrown into a vertical position and finally overturned, so that in the peak west of Stob Coire nan Lochan the andesites of group 1 overlie the rhyolites of group 2 (Pl. XXXIII, Section IV). The diversity of the volcanic sequence brings out this structure very clearly, and under favourable conditions of light it can be detected even from the Glen Coe road (Pl. XXXII).

The disturbance just described continues for some distance to the south, as may be seen from the manner in which the outcrops of the various groups cross the contours. In Beinn Ceitlein too the rhyolitic rocks appear to assume a vertical position near the fault, although a few hundred yards away their inclination is quite low.

North of Bidean nam Bian, one may notice the steep easterly or south-easterly dip of the volcanic rocks, which is prominently displayed where the base-line of the group leaving the fault, swings across Glen Coe above Loch Achtriochtan.

In Aonach Eagach the lavas again assume a vertical position where they once more come into contact with the fault which here, among other things, cuts out the basement conglomerate of the series (fig. 11, p. 658).

In Coire Càm, upon the other side of Aonach Eagach, the Volcanic Series is suddenly overturned in the immediate proximity of the fault. The andesites at one point plunge steeply beneath the basal conglomerates, which, with their associated grits and shales, dip at about 70° under a small inverted patch of the schist floor (figs. 11 & 12, pp. 658 & 659). By tracing the reddened tops of successive lavas in the cliff-face of this corrie, it is possible to show that the inversion just described is a sharp flexure confined to the vicinity of the fault. Beyond this the beds dip steeply away from the dislocation, the position of which is marked in Meall Dearg, as at so many other places, by the fault-intrusion in the manner to be described later (p. 656).

The overturned base of the volcanic group is seen, but not very clearly, in Coire nan Lab to the east (fig. 11, p. 658).

In Coire Mhorair, farther east again, the lavas are steeply overturned, for their junction with the Schists, marked by basal sediments, sweeps out distinctly farther northwards in the valley-floor than on the two flanking ridges. The fault lies a little to the north of the base-line of the volcanic group in this corrie, and its position is well defined, as the subsequent detailed descriptions will show (fig. 9, p. 654).

In Coire Odhar-mhòr, dips measured in the basal beds of the volcanic series, and in shaly intercalations at higher levels, range from 40° to 80° away from the fault, the position of which is again well marked (fig. 9).

From Sron a' Choire Odhar-bhig to Sron na Creise the volcanic rocks are steeply upturned, at angles averaging 50°. Along this part of its course the base of the group is generally about three-quarters of a mile distant from the fault, although roughly parallel to it.

In the Cam Ghleann the lavas and breccias of the volcanic group are undisturbed; but on the slopes of Meall a' Bhuiridh they are suddenly upturned in the immediate vicinity of certain quartz-veins which here mark the position of the fault.

Yet, while it is true that the great mass of the Old Red volcanic and sedimentary rocks of Glen Coe occupy a compact area, included within the great boundary-fault, there are a few small outlying patches which cannot be ignored:—

(1) An isolated outcrop of quartzite breccia north-west of Stob Mhic Mhartuin (fig. 7, p. 649).

(2) A small outcrop of rubbly breccia, consisting mostly of fragments of quartzite, with a few bits of igneous rocks, on the western flank of Sron a' Choire Odhar-bhig, exposed near the foot of the ridge and between two branches of the boundary-fault (fig. 9, p. 654).

(3 & 4) Breccias on the slope of Sgor nam Fiannaidh and at the head of Gleann Chàrnan, already described, p. 621.

(5) Several isolated patches of breccia and rhyolite between the two branches of the fault on Beinn Ceitlein.

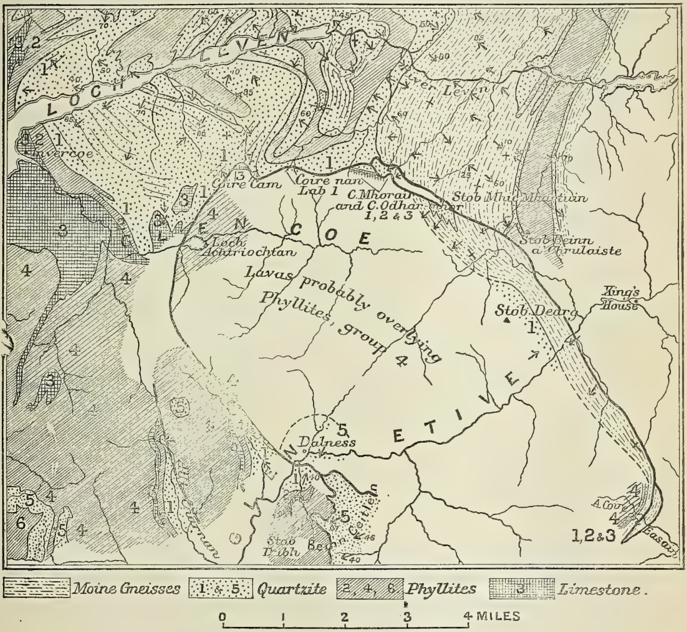
In the first two instances cited above it is exceedingly difficult to understand the relation of the breccias to the topography buried beneath the volcanic rocks, unless it be admitted that the deposits represent material which has fallen down an earthquake-fissure or into some other hollow of equally special character (*cf.* p. 622).

There is no difficulty, however, in regarding the other patches as outliers occupying inequalities in the pre-volcanic surface of erosion. It is probable enough that, originally, the volcanic rocks of Glen Coe spread out for a considerable distance beyond their present limit, and they may even have been continuous with the lava fields of Lorne.

(2) Distribution of the Highland Schists in relation to the faulting.—It is beyond the scope of this paper to discuss the tectonics of the Highland Schists of the district, but a glance at

fig. 2 will show how important is the influence that the cauldron-subsidence has had upon the outcrops of the various belts of schist found within it.

Fig. 2.—*Sketch-map of the Highland Schists of the Glen Coe district, showing the effect of the boundary-fault on the distribution of the schists.*



Outside the fault, near the mouth of Glen Coe we can make out the following local succession in descending order (as the beds lie):—

4. Thick phyllites.
3. Thick limestone and calcareous schists.
2. Thin black schist and phyllites.
1. Thick quartzite.

These rocks, for the most part, dip steeply south-westwards.

The same succession is thrown forward to the north-east in the faulted area, to an extent which indicates a drop of some thousands of feet.

The thick phyllites (4) occupy the hill-slopes beneath the lava-

flows on both sides of Loch Achtriochtan, inside the cauldron, and are brought by the fault into juxtaposition with all three of the lower groups lying outside the fault.

Group 3, the limestone, is exposed in a small patch at the bottom of Coire Càm, where it lies well in advance of the unfaulted outcrop, although the latter overtops it on the summit of the ridge to the extent of 1000 feet.

Group 1, the quartzite, is probably represented by the small outcrop at the base of the lavas in Coire nan Lab.

In Coire Mhorair and Coire Odhar-mhòr there is an extensive exposure of the quartzite (1), thin phyllite and black schist (2), and limestone (3).

Beyond this, to the east, much of the ground between the lavas and the fault is occupied by flaggy, quartzo-micaceous 'Moine Gneisses'; the outcrop of the quartzite (1) can, however, be traced along the foot of Stob Dearg; and in Allt Coire an Easain, farther south-eastwards, all the four zones of Glen Coe seem to reappear. The supposed equivalents of groups 1, 2, & 3 are here much thinner than in Glen Coe, but this thinning is quite in keeping with the behaviour of the various groups in this part of the Highlands. The dip of the Schists in the Allt Coire an Easain section is towards the east, wherefore it appears likely that the greater part of the volcanic rocks of the sunken area rests upon the thick phyllites of group 4.

At Dalness, however, within the fault, exposures of quartzite jut up sporadically through the lavas. Probably these are portions of a quartzite group, overlying the phyllites of group 4, and represented, outside the fault, by outliers (group 5 on the map) on the summit of Stob Dubh and other prominent hills in the neighbourhood. The quartzite between the two branches of the fault in Beinn Ceitlein is also probably referable to group 5.

The preceding description has been given, in order to enable the reader, with the help of the sketch-map (fig. 2, p. 627), to contrast the general distribution of the Highland Schists within the faulted area with that in the surrounding country.

The effect of the branch fault, running through the Allt Chàrnan valley, is also clear. It throws down the thick phyllites of group 4 to the east against quartzites, banded phyllitic rocks, and limestone (calc-silicate hornfels), which are believed to represent groups 1, 2, & 3, respectively, of Glen Coe.

In two other important sections, one at Stob Mhic Mhartuin and another at Stob Beinn a' Chrùlaiste, differences both of strike and of lithological character distinguish the Schists on the two sides of the fault-plane. These sections are described in detail in the sequel, where a fuller discussion of the behaviour of the fault in relation to the Schists south-east of Dalness will also be found.

(3) The inclination of the boundary-fault.—The inclination of the main fault surrounding the cauldron is a point of some interest. Along the northern front the fault generally overhangs the cauldron at angles varying from 70° to 50°, measured

from the horizontal; but along the opposite margin it inclines towards the subsidence (Pl. XXXIII). The fault-planes on either side are thus roughly parallel, and one may imagine that the cylindrical downthrown mass originally had perpendicular walls, and then was tilted bodily into its present inclined position. In support of this hypothesis we may quote the prevalent southerly dip of the lavas in the heart of the cauldron. At the same time, the outer branch of the fault on the slopes of Beinn Ceitlein has a markedly reversed hade; and, as it is quite impossible in this case to explain the phenomenon on any hypothesis of later tilting, it appears not improbable that the local reversal of hade elsewhere may also be an original feature. The frequent sharp flexuring, and even inversion, of the lavas in the vicinity of the fault shows that the interior mass yielded as it sank, and it is quite conceivable that this permitted an over-riding of the subsiding area, to use an expression introduced by Suess.

(4) Mechanical evidence of faulting.—At a few favoured points along the line of the fault there is clear evidence of intense shearing, leading finally to the production of 'flinty crush-rock.'

The macroscopic characteristics of this rock are flinty lustre, dark colour, frequently conspicuous flow-banding, and an almost invariable connexion in the field with obvious signs of shearing. Under the microscope the banded structure is often strongly pronounced, and the rocks themselves are found to be richly charged with fragments derived from the adjacent shear-zone, fragments which are as a rule in a mylonized, crushed, or disintegrated condition. In the Glen Coe district, in cases where flinty crush-rock has been produced from quartzite or quartz-schist, a large proportion of the rock consists of separate glistening grains of quartz, which can be detected on a fractured surface even without the aid of a pocket-lens.

Since flinty crush-rock plays an important part in the geology of Glen Coe, we may indicate briefly the main points in regard to its mode of occurrence in certain other localities. Flinty crush-rocks have been described from the Cheviot granite of Lower Old Red Sandstone age, and also from certain pre-Torridonian lines of movement in the North-West Highlands.[1] In the latter region, besides the black flinty crush-rocks, which are in obvious genetic connexion with planes of dislocation, there are found occasional

'dark-brown, grey or black strings, rarely more than an inch thick, which do not displace the folia crossed by them. These strings sometimes bulge out in rounded projections, or end bluntly and look like intrusive felsites. They are, however, confined to zones which have been crushed, and it seems probable that many of them are isolated on all sides by the adjoining rocks. It is difficult to see how they can be intrusions of true igneous rock. Perhaps by the intensity of the crushing near them sufficient heat may have been generated to fuse small portions of the rock.'

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[1] C. T. Clough, 'The Geology of the Cheviot Hills' Mem. Geol. Surv. 1888, p. 22; C. T. Clough & E. Greenly, in 'The Geological Structure of the North-West Highlands of Scotland' Mem. Geol. Surv. 1907, pp. 249–50.

In fact, these strings are probably nothing else but extreme types of flinty crush-rock, although some of them (4281, 5270),[1] as might be expected from their field-relations, reveal under the microscope the beginnings of a crystalline structure in their ground-mass and so indicate that they were at one time partly fused. The enclosures in this ground-mass are fragments of the neighbouring rock, and they show the same advanced cataclastic structures as those that are typical of the enclosures in the flinty crush-rocks occurring along definite shear-zones in the vicinity.

Flinty crush-rocks are known as 'trap-shotten' among the charnockite gneisses in Southern India, and their nature has been elucidated by Sir Thomas Holland[2]:—

'The so-called "trap-shotten" bands coincide with lines of dislocation, and the black tongues and films which superficially resemble compact "trap" have the microscopical characters of mylonite which has been hardened—fritted and rarely half-fused—by the heat generated through the dislocation being confined to narrow bands, and thereby causing a higher local rise of temperature than would result from a general deformation of the rock-mass.'

By crushing a specimen of charnockite, and then subjecting it to a very imperfect fusion, Sir Thomas Holland was able to reproduce experimentally the blackness, tachylytic lustre, and structureless base, containing numerous angular enclosures of quartz, which are so characteristic of the 'trap-shotten' bands in the charnockite gneisses.

The evidence in Glen Coe corroborates the conclusions which have been arrived at in the districts mentioned above. It can be shown that here, as elsewhere, dark flinty or tachylitic rocks with perfect flow-structure have been produced by the shearing of various types of rock, quite independently of igneous action of any sort (p. 650). A clear example is also known, in which flinty crush-rock of normal structure has left the fault-plane with its accompanying shear-phenomena, and has been injected as a viscous body into the surrounding schists (p. 653).

When a microscopical investigation is made into the nature of the sheared material which accompanies the flinty crush-rock, it is found that this material has not always one particular structure. In the North-West Highlands the materials of the disintegrated rock sometimes show marked deformation and strain-structures, which become obvious when a thin slice is examined between crossed nicols. Here the intermediate product is apparently somewhat mylonitic in character; and this also appears to be the case with the 'trap-shotten' bands of India, so far as can be judged from the descriptions. In the Cheviot and Glen Coe examples, however, mylonization is not prominent; but a trituration, resulting in the production of a pseudo-grit, is apparently the first stage in

[1] The numerals in parentheses refer to the corresponding numbers of the microscope-slides in the Geological Survey collection.

[2] 'The Charnockite Series, a Group of Archæan Hypersthenic Rocks in Peninsular India' Mem. Geol. Surv. India, vol. xxviii (1900) pp. 198, 248.

the development of the flinty crush-rocks (12329). The isolated quartz grains, so characteristic of many of the Glen Coe crush-rocks, have been produced in this manner, and their freedom from strain-shadows, when embedded in a matrix showing perfect flow-structure, furnishes microscopical proof that this matrix transmitted stress as a fluid (12332). This in itself is strong additional evidence in favour of the view that flinty crush-rocks have undergone partial fusion due to mechanical causes. Incipient crystallization has also been noticed in the base of the crush-rocks from the Glen Coe district (11464 & 12934), but it is not impossible that the appearances observed may be the result of contact-alteration due to neighbouring igneous masses.

In most cases the texture of the ultimate base of these crush-rocks is too fine-grained to be resolved, even with the aid of a $\frac{1}{12}$-inch objective: no more can be recognized, in fact, than that much of the material between the larger grains is of the nature of a fine rock-powder. It is interesting to note, however, that many of the flinty crush-rocks of Glen Coe (12332) carry an innumerable swarm of minute black specks distributed evenly enough throughout their ground-mass, and that a similar feature has been described by Sir Thomas Holland as characteristic of the 'trap-shotten' bands of India.

Flinty crush-rock along definite fault-planes in the Glen Coe district may attain the thickness of an inch. In connexion with local shear-belts flanking the major dislocations it is generally found as a mere shred or film. In the one observed case of independent intrusion away from a movement-plane, the rock formed a highly irregular sheet, sometimes exceeding an inch in thickness.

It is only at comparatively few points that flinty crush-rock has been found along the course of the Glen Coe boundary-fault. Good examples have been noticed in both branches of the fault at and near Stob Mhic Mhartuin, and also in the Dalness and Cam Ghleann sections, details of which are given on pp. 650–53 & 660.

Much more commonly the position of the fault is marked by an ordinary loose fault-breccia, or 'ruttle,' which weathers out as a line of hollow traversing the hill-slopes. This, the normal condition of affairs, is exemplified along the whole line between An t-Sron and Dalness, and also in many localities north of Glen Coe. Shattering of this type is, however, quite unconnected with the production of the original Glen Coe fault, since it affects innumerable north-north-east porphyrite dykes which cross the fault without any other sign of disturbance, and are, accordingly, of later date than the period of subsidence. Indeed, where these dykes cross the unshattered exposures of the fault—as, for example, in the Stob Mhic Mhartuin and Cam Ghleann sections—they are themselves quite free from any marks of disturbance, despite the intense shearing and trituration affecting the rocks which they traverse. Reference will be made to another clear indication that the open shattering along the fault-line is a later and trivial phenomenon, when the 'fault-intrusions' come

to be described (p. 635). It is clear, in fact, that the Glen Coe fault has proved a ready guide to all later earth-tremors which have affected the district, and that the rocks in and near it have suffered accordingly. Among these latter may be mentioned a basalt dyke of presumably Tertiary age, which has been intruded along the fault-plane some distance north-west of Dalness, and has later been brecciated in the self-same manner as the porphyrite dykes of Old Red Sandstone age already mentioned.

The shattering which has been induced along the line of the boundary-fault is, therefore, of small significance as an independent phenomenon; but it has helped us greatly in tracing the course of the fault. In fact, where the original fault-line has not been used again by later disturbances, it is sometimes very difficult to detect: for the rocks are by no means invariably sheared in its vicinity to the same extent as at Stob Mhic Mhartuin. Sections will be described later, in the neighbourhood of Dalness, where there is such an absence of disturbance along the outcrop of one important branch of the fault, that its existence can only be proved by the discordant relation of the Highland Schists upon its two sides.

At one point along its course—namely, on the eastern slope of Meall a' Bhuiridh—the position of the fault is marked by an abundance of quartz veins. This, however, is most unusual, and, like the smashing, must be due to subsequent changes affecting the original fault-rock, for one of the later north-north-easterly porphyrite dykes is pierced by the veins.

Where consolidated igneous masses have been exposed to the stresses which accompanied the Glen Coe subsidence, they have, as a rule, been sheared and eventually broken down into flinty crush-rock, in just the same manner as the schists into which they are intruded. This behaviour is clearly seen in an important intrusion which extends westwards from Stob Mhic Mhartuin, and lies to the north-east of the outer of the two branches into which the Glen Coe fault is divided in this locality.

In one instance, however, strongly marked shearing of a different type has been noticed in an igneous rock. In this case the most obvious result of the stresses has been the production of long parallel ribbons, derived from the destruction of the ferromagnesian phenocrysts. The shear-zone in which these ribbons occur is only a few inches wide, and is well seen in the steep slopes on both sides of Allt Coire an Easain, where it furnishes the main evidence for the inner of the two branches of the fault shown upon the map in this locality. The zone is vertical and strikes in a general north-north-east and south-south-west direction.

(5) The fault-intrusion, and its relation to the other plutonic rocks of the district.—The Glen Coe volcanic rocks lie on the northern margin of one of the largest granitic intrusions of Scotland (see fig. 1, p. 614). This great mass, the Etive Granite, has

been separated by Mr. Kynaston into an earlier more basic rim, the Cruachan Granite, and a later, coarser, porphyritic, and more acid interior, called the Starav Granite.[1]

Here we are concerned merely with the Cruachan Granite, which, as Mr. Kynaston has shown, extends from the south far into the Glen Coe cauldron, and produces marked alteration in the volcanic rocks.[2] This northern prolongation of the granite passes transgressively beneath the lavas of the two Buachailles, which serve as its roof, now, it is true, largely removed by erosion. It has not, however, tilted these overlying lavas, so far as can be ascertained in many clear sections, and nowhere do we find indications of its base (Pl. XXXIII). It would not be correct, therefore, to describe it as a laccolite.

The Cruachan Granite within the district embraced by Pl. XXXIV is mainly of one uniform type, which is best described as a pink hornblende-granitite rich in plagioclase. Two conspicuous varieties are also included within the mass, but it has not been possible to map them out, owing to the absence of definite boundaries between them and the normal rock. The one, a pink granitite of more acid composition than the normal rock, and confined to certain parts of the high ground, requires no further description here. The other is a grey tonalitic variety occurring on the margin of the mass, in the district south of Allt Coire an Easain.

Under the title of 'fault-intrusion' we include a series of more or less isolated masses of granitite, tonalite, and porphyrite, which form an interrupted girdle round the sunken area (Pl. XXXIV). Although the special name here introduced is justified, on account of the very intimate relations which exist between the girdle of intrusion and the boundary-fault, the evidence is strong that the fault-intrusion is merely, as it were, an advance guard flung out in front of the main mass of the Cruachan Granite. It presents four principal types: namely, the grey tonalite and the normal pink granitite already mentioned in connexion with the Cruachan Granite, and also coarsely crystalline grey and pink porphyrites.[3] The difference in composition between the types of porphyrite is probably less than that between the tonalite and the granitite; but, in most localities where the fault-intrusion is represented by porphyrite, the latter is of one prevalent variety, grey or pink as the case may be.

A feature of the fault-intrusion, which in some localities is exceedingly conspicuous, is the number of xenoliths enclosed by it.

[1] The name Starav has been taken from the beautiful mountain, Ben Starav, entirely composed of the central granite. In previous descriptions the central intrusion has been termed the Glen Etive or Blackmount Granite; but both these names have had to be abandoned as geographically misleading.

[2] 'Summary of Progress of the Geological Survey for 1900' (1901) pp. 82, 83.

[3] The types of 'fault-intrusion' here termed porphyrite resemble closely in the hand-specimen certain of the more coarsely crystalline dyke-rocks, but it is probable that the former include rocks of 'acid' composition (that is, containing more than 65 per cent. of silica).

The great majority of these xenoliths are highly metamorphosed fragments derived from the Highland Schists.

The relation of the fault-intrusion to the fault will now be considered in greater detail. Enough has been said already to justify a belief in the Glen Coe subsidence, and to indicate in many places the precise position of the boundary-fault. The distribution of the fault-intrusion is in obvious relation to the course of this fault: in brief, the intrusion follows along its outer side. It often occurs as a broad dyke-like mass, sharply bounded along its inner margin by the fault, but with an outer margin of very irregular form: often, too, it occurs in isolated masses, of many different shapes, which flood the country-rock for a distance of about a mile from the fault, but farther away are almost unrepresented.

If we leave out of consideration the big but compact mass of the Cruachan Granite, invading the south-eastern corner of the area, only three or four small outcrops of the fault-intrusion are known within the boundary-fault. These three or four little outcrops comprise a small mass intruded into the andesites at the foot of Meall Dearg in Coire Càm, apparently along a branch of the fault; a second small mass to the east of An t-Sron, also intrusive into andesites and close to the fault; and an ill-defined patch on the south side of Glen Etive, a little above Dalness.

The contact-metamorphism induced by the fault-intrusion is similarly restricted, and the lavas and schists within the cauldron-subsidence have escaped almost untouched, with the exception of the rocks in the neighbourhood of the large offshoot of the Cruachan Granite and those in immediate contact with the small masses mentioned in the preceding paragraph.

Along its external boundaries the fault-intrusion not infrequently becomes finer in grain, or even shows actual chilling. In contact with the boundary-fault the latter change is invariable, and the rock passes into a fine-grained porphyritic marginal facies—a fact which clearly proves that the intrusion is not of earlier date than the faulting.

The smooth chilled edge, which the intrusion presents against the fault, is so characteristic a feature that it can be safely used, in return, to fix the position of the fault in places where, owing to the breadth of the intrusion, other evidence is obscure. Thus, between Dalness and Bidean nam Bian, so long as the fault-intrusion is of very moderate dimensions, it is obvious that its even north-eastern margin is chilled against a powerful fault, throwing lavas on the north-east down against schists on the south-west. On the other hand, northwards, on An t-Sron, where the breadth of the fault-intrusion is no less than a mile, the precise position of the fault can only be inferred from the smooth course followed by the inner chilled margin of the fault-intrusion, and from the later shattering which has been guided by the old line of weakness.

In this long section between Dalness and An t-Sron, and again

at many points north of Glen Coe, it is important to notice that the later movement along the old fault has had so insignificant an effect that it has not cut out the original chilled edge of the fault-intrusion; nor, as already remarked, has it shifted the north-north-easterly porphyrite dykes, which cross the fault-line.

In An t-Sron, and also in Meall Dearg and Sron Garbh, north of Glen Coe, there is of course independent evidence that the boundary-fault, if not actually at the chilled edge of the intrusion, must at all events be very close at hand. The prolongation of the fault-line between Stob Beinn a' Chrùlaiste and the Cam Ghleann, and between this glen and the eastern flank of Meall a' Bhuiridh, is, however, on a somewhat different footing. At each of the three places named the fault is clearly defined, and against it the fault-intrusion is distinctly chilled. In the intervening ground, however, exposures are poor, so that it has not been found possible to locate the fault precisely; and we can only say, in reference to these tracts, that the fault-intrusion stretches in a continuous belt from Stob Beinn a' Chrùlaiste through the Cam Ghleann to Meall a' Bhuiridh, and that its inner margin is, as a rule, an even line. An exception to this rule is to be noted in the exposures on the hilltop east of the Cam Ghleann; for here the fault-intrusion pierces the schists along its inner margin irregularly and without chilling. The schists of this exposure, however, almost certainly lie outside the fault, since their strike is at right angles to that found in neighbouring outcrops on the south-west, which are clearly within the boundary-fault.

The fault-intrusion continues southwards from Meall a' Bhuiridh; but before long it loses its main distinguishing character, and ceases to show a chilled interior margin, although probably still bounded on this side by the fault-plane. A little farther on it joins the Cruachan Granite, at the point where the latter sweeps across the fault into the sunken mass within.

We are now in a position to discuss the details of the internal constitution of the fault-intrusion, and the relation subsisting between this complex and the contiguous portion of the Cruachan Granite.

Beginning at the south-eastern corner of the area, a branch of the pink granitite leaves the main Cruachan mass and extends north-north-eastwards, being bounded on the north-west by an even line, presumably the trace of the fault. It is not chilled, however, against the plane which is supposed to represent the fault in this locality.

About a mile to the north of the point where this pink granitite diverges from the main mass of the Cruachan intrusion, it passes gradually into the grey tonalite. The passage can be followed in the cliff facing the River Bà to the north of Allt Coire an Easain. The change of type is rather sudden, being completed within a space of 20 yards or so; but within these limits the transition is perfect.

This grey tonalite stretches north-north-westwards, in a continuous belt without sensible variation, to the foot of Stob Beinn a' Chrùlaiste. At two points along this course, namely on Meall a' Bhuiridh and in the Cam Ghleann, there are clear sections of the boundary-fault, and the accompanying tonalite exhibits a typical chilled inner margin.

On Stob Beinn a' Chrùlaiste the grey tonalite merges into coarse grey porphyrite, packed with felspar phenocrysts. This rock is chilled against the fault, and also along its outer irregular margin. In Stob Mhic Mhartuin the grey porphyrite reappears with exactly the same relations.

From Coire Odhar-mhòr westwards the fault-intrusion is represented in the main by pink porphyrite, associated with a considerable mass of pink granitite. The latter does not come into actual contact with the fault, and its junction with the intervening porphyrite can readily be traced. This junction is exposed at the base of Sron Garbh, and is not quite sharp, being marked by a foot or so of hybrid rock. Probably, in this case, the granitite is of somewhat later date than the porphyrite.

The innumerable intrusions of pink porphyrite between Garbh Bheinn and Glen Coe are especially interesting, for in this district the porphyrite frequently fails to show any sign of chilling away from the fault-line, and the schists which it traverses are altered and permeated to a remarkable degree.

In An t-Sron the pink granitite is found in intimate association with grey tonalite. In the vicinity of the fault a chilled margin is always developed, as elsewhere.

South of the River Etive the fault-intrusion is represented by the grey type of coarse porphyrite; and, about a third of a mile south-south-east of Dalness, a definite line can be drawn between this and the adjoining pink granitite of the Cruachan mass. The exact junction is not exposed, but the two rocks retain their distinctive features within a foot of one another; and specimens taken from the mass of the porphyrite, even at a distance from the junction, show marked contact-alteration.

These facts seem to be most easily harmonized on the assumption: (1) that the fault-intrusion came from the same deep reservoir as the Cruachan Granite, and that differentiation in this reservoir had already, before intrusion, separated out two distinct types, now represented by grey and pink rocks respectively; (2) that during the long process of intrusion to higher levels, sufficient time occasionally elapsed for the more or less complete consolidation of outlying portions before later arrivals appeared; and (3) that the pink granitite, in some cases at least, was the last to appear.

It has been stated above that the contact-metamorphism of the schists due to the fault-intrusion is practically limited to the rocks outside of the Glen Coe cauldron. For instance, the phyllites inside the fault on the slopes above Loch Achtriochtan have

undergone only an insignificant induration, while the rocks of the same group outside the fault show traces of alteration for about half a mile from the An t-Sron granitite, and at the actual junction with the granitite have been converted into andalusite-hornfels. Without entering into a detailed description of this contact-alteration, it may be said that the mineral changes are quite similar in kind to those, already described by Dr. Teall,[1] in the Highland Schists at the southern margin of the Cruachan Granite, in the neighbourhood of Loch Awe.

An interesting feature observed between An t-Sron and Stob Mhic Mhartuin is the bright pink or red colour frequently assumed by the schists included within the peripheral zone of alteration. In the case of the andalusite-hornfels this coloration is relatively slight, and is due to the development of abundant fresh orthoclase, evidently at the expense of the original constituents of the rock. There has been, however, in many places an injection of granitic magma into the phyllites, in the form of highly felspathic pink veins. The veins follow the foliation-planes of the phyllites, or transgress them but slightly; consequently they illustrate on a small scale the lit par lit type of injection. But the introduction of material from the invading magma takes place on a greater scale in the case of the quartzite, and is particularly well exemplified in the country between Garbh Bheinn and the watershed north of Glen Coe.

This is a quartzite country, riddled with small irregular masses of pink porphyrite, for the most part packed with xenoliths, as is so frequently the case with outcrops of the fault-intrusion. At many points the quartzite becomes bright pink or red, owing to the introduction of felspar, and this has locally proceeded to such an extent as to yield a pseudo-granitoid rock. The clearest sections exhibiting the connexion of this permeation with the injection of the pink porphyrite phase of the fault-intrusion occur in the stream-courses south-west of Garbh Bheinn. Remarkable intrusion-breccias are here exposed, containing large blocks of schist enclosed in a porphyrite matrix. In some places this matrix has derived so many quartz grains from the quartzite that it might easily be taken for red felspar-bearing quartzite itself, and yet it was evidently at one time fluid enough to flow around and enclose xenoliths. A close inspection of many of the quartzite enclosures in these breccias shows that the constituent grains increase in size as they approach the margin, and then are separated by the intervention of felspathic material coming from the porphyrite. Here the porphyrite receives quartz grains from its xenoliths, and an unbedded rock results. In other cases, however, felspar has been introduced into the quartzites without disturbing their bedding, while the rocks are so veined with recognizable porphyritic substance that the connexion between the felspathization and the intrusion of the porphyrite seems

[1] 'The Geology of the Country near Oban & Dalmally' Mem. Geol. Surv. 1908, p. 140.

unquestionable. Where it traverses reddened patches of this character, the porphyrite, one need scarcely add, shows no indication of chilling at its margin. It is interesting to note that in the permeation-phenomena outlined above, alkali-felspar plays the predominant rôle, and it seems necessary to admit the operation of diffusion, governed by some selective principle.

In addition to the Cruachan mass, there is another important granite, with which the fault-intrusion comes into contact. This is the great Moor of Rannoch Granite, lying to the east. Its interior portions, as seen in the neighbourhood of Kingshouse, consist of grey hornblende-granitite; but, for a considerable breadth near its margin, it is free from hornblende, and contains large pink orthoclase crystals. In many parts the mass shows a well-marked parallel arrangement of its mineral constituents. Its junction with the fault-intrusion is of a very intricate type, and is well exposed in both the Coupall[1] and the Etive rivers. The interpretation of these difficult sections we owe entirely to Mr. Grabham. He has shown that, although the margin is of the hybrid type, the fault-intrusion is certainly the later rock. The most convincing section is that in the Coupall River, where at one place scattered blocks of the Rannoch Granite lie in the grey fault-intrusion and each block possesses a different orientation, as shown by its mineral banding.

(6) The early fault-intrusions.—For a mile and a half to the west of Stob Mhic Mhartuin a mass of rock is indicated on the general map under the title of 'early fault-intrusion.' It is a grey hornblendic porphyrite, frequently charged with xenoliths, but still quite readily distinguishable from the previously described grey fault-porphyrite of the fault-intrusion. For one thing, it is finer in texture and less packed with phenocrysts. Its main characteristics are summed up in its designation. It is a 'fault-intrusion', since, all along its course, its inner margin is chilled against an outer branch of the boundary-fault, which is marked by a line of intense shearing of the schists culminating in the production of flinty crush-rock. It is 'early' because, unlike its more important neighbour, it has suffered from renewed shearing movement which came on after its complete consolidation. Sometimes along the margin, sometimes a little distance from it, and in many cases in the very heart of the rock, shear-bands may be detected crossing this early porphyrite. On a fractured face it may be observed that the phenocrysts are broken and drawn out; the porphyrite in this stage assumes a dark colour, and is traversed by threads and bands of flinty crush-rock formed by the destruction of its own material.

This is not all. On Sron a' Choire Odhar-bhig the fault-intrusion, *sensu stricto*, occupies the whole space between the two branches of

[1] The exposures of Rannoch Granite in the Coupall River are small and outside the main mass. They are not indicated on the map (Pl. XXXIV).

the fault, each marked by a line of flinty crush-rock; and a little way down the western face of the ridge a junction with the early fault-porphyrite is exposed (fig. 9, p. 654). Here the contrast between the relations of the two porphyrites is clear, since the earlier intrusion on the north is greatly sheared along the contact-plane, while its fellow on the south is quite unmoved.

The same early fault-intrusion comes into conjunction also with the pink granitite mass which lies at the foot of Sron Garbh. The junction is known only in one stream running down the scree-slope from the east into Coire Mhorair. Microscopic examination of a specimen from this stream shows that the granitite has induced marked contact-metamorphism in the porphyrite, including the replacement of the hornblende phenocrysts by aggregates of biotite (12358).

A distinct but much smaller mass of sheared early fault-intrusion lies immediately outside the southern branch of the fault in Coire Odhar-mhòr (see figs. 9 & 10, pp. 654 & 655). Here the 'early' age of the intrusion is again clear: for the main fault-porphyrite cuts across it obliquely, without itself showing any sign of disturbance.

An outcrop of dark diorite exposed in the Cam Ghleann, a little distance within the main boundary-fault, probably also belongs to the category of early fault-intrusions. It lies with an even base upon a lowly inclined plane, marked by intense shearing of the underlying schists. This plane dips down stream, away from the centre of subsidence, and is evidently connected with the system of faults which surround the sunken area. The diorite here shows a marginal felsitic facies in contact with the plane. No clear signs of movement have been detected in this marginal rock, and the main outcrop of diorite is certainly quite unsheared. The rock is, however, so distinct in appearance from the big outcrop of grey tonalite, representing the fault-intrusion proper in this neighbourhood, that it almost certainly belongs to a distinct epoch in the history of the subsidence. In the next paragraph, reason will be given for believing that this epoch was of early date.

A dark diorite similar to that of the Cam Ghleann, just described, crops out on both sides of Allt Coire an Easain. It has already been mentioned, on account of the peculiar indications of shearing which its inner margin exhibits. In its main relations it is a typical fault-intrusion, for it has a smooth almost vertical inner margin, excellently exhibited on the bare hill-slopes, and in the immediate proximity of this margin it passes into a fine-grained porphyrite. There can be little doubt that this smooth face is determined by a fault-plane. The chilled margin, as already noticed, is intensely sheared. The curious fact about it is that the shearing has not given rise to the type of brecciation which

culminates in flinty crush-rock; on the other hand, it has deformed the phenocrysts, especially the ferromagnesian elements, which it has drawn out into thin parallel films consisting of aggregates of biotite-crystals. The difference between the streaking of the phenocrysts in this instance, and the intimate crushing of the early fault-intrusion on the northern margin of the cauldron, is very marked, and points to an important difference in the conditions under which the shearing stresses acted in the two cases. It is probable that the streaky margin of the Allt Coire an Easain diorite was sheared before the main mass (of the same intrusion) had risen along the fault, and that it was caught by the movement when the matrix was still pasty. If this supposition is correct, the shearing of the diorite in itself scarcely suggests an early date for the intrusion. On the south, however, evidence is forthcoming, since in this direction the dark diorite is clearly cut across by the pink granitite, which, as has been shown, merges insensibly northwards into the normal grey tonalite of the fault-intrusion proper.

(7) The dykes, and their relation to the cauldron-subsidence.—From the days of MacCulloch the multitude of dykes in Glen Coe has always been a cause for remark. They are so abundant that, in some places, they actually bulk as largely as the country-rock, and consequently, in order not to obscure the other geological features of the district, they have been omitted from the general map. A comprehensive view of their distribution may be obtained by an inspection of fig. 1 (p. 614), but in localities such as Glen Coe, where they cluster thickly, scarcely more than one-tenth of their actual number is represented on the map.

The vast majority of these dykes are of later date than the fault-intrusion, and traverse the schists, the lavas, and the Rannoch and Cruachan granites alike, always exhibiting clear evidence of chilling at their margins. Their prevalent trend is north-north-east and south-south-west, and it remains unaffected by the boundary-fault: except that very occasionally some of them turn along it for a space, following the fault just as they would any other old line of weakness. Some are broken, it is true, by the shattering, which often characterizes the fault-line; but, as has been explained above, this shattering is later than the actual subsidence. They likewise traverse the lavas upturned at the margin of the cauldron, without themselves being tilted from the vertical. Occasionally, indeed, a slight hade is discernible: as for instance, near Alltchaorunn in Glen Etive; but, throughout the district generally, they maintain a remarkably uniform verticality, witnessed by the straight courses which they follow across mountain and glen.

By far the greater number of these dykes are porphyrites distinguished by phenocrysts of plagioclase, and one or more of the ferromagnesian minerals (hornblende, biotite, augite or hypersthene). The ground-mass is fine-grained, and consists of felspar, with a second generation in many cases of the ferromagnesian minerals,

and usually a little quartz. The rest of the dykes comprise quartz-porphyries, felspar-porphyries, and several varieties of lamprophyre. There is, thus, a considerable range in composition, but the various rock-types form a connected suite without any marked break. This bespeaks consanguinity, and so, too, does the close association of the various rock-types in one dyke-belt, and even, as is frequently the case, in one composite dyke. Besides this, the assemblage of types can be matched in the dykes following many other well-known granodioritic intrusions, both British and foreign.

Mr. Kynaston has shown that, although numberless dykes enter the Cruachan Granite, 'only one small porphyrite dyke' has been observed in the whole extent of the Starav Granite. He supposes, therefore,[1] that the dyke-phase of intrusion may have intervened between the uprise of the two plutonic masses. Our own observations certainly favour this interpretation, since a specimen from a porphyrite dyke cutting the Cruachan Granite near the margin of the Starav mass shows strong evidence of contact-alteration (13762).[2]

[1] 'Geology of the Country near Oban & Dalmally' Mem. Geol. Surv. 1908, p. 87.

[2] [Since the reading of this paper we have taken an opportunity to study the phenomena more fully in the field, and have found that the Starav granite is clearly later than the great suite of north-north-east dykes. The junction of the two granites is exposed for over a quarter of a mile in Allt nan Gaoirean, the southernmost tributary on the right bank of the River Etive shown on the map (Pl. XXXIV). In this burn the Cruachan Granite is cut by dykes, while the Starav Granite is not. The dykes show distinct signs of contact-alteration in the hand-specimen, and microscopic examination of thin slices confirms it (14175, 14177-78). The junction-plane of the granites is here a fault, which is accompanied by shearing along the junction, and also along subsidiary parallel shear-planes traversing both Cruachan Granite and dykes alike. The section is thus less decisive than would otherwise have been the case, but at the same time the faulting and shearing are of interest in another connexion.

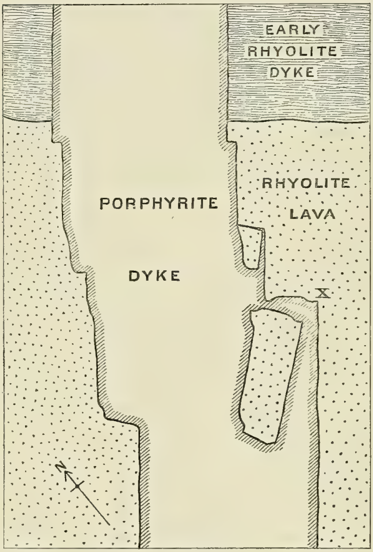
Allt Dochard, flowing obliquely across the junction-plane a little south of the area included in Pl. XXXIV, furnishes corroborative evidence. Dykes are here abundant in the Cruachan Granite quite near to the Starav margin, while they are absent in the latter intrusion where it in turn forms the bed of the stream. Although they consolidated with typical hypabyssal structure, these dykes are traversed, in common with the Cruachan Granite, by numerous aplite veins. Examined under the microscope, thin slides of some of them show evident contact-alteration (14181, 14182, & 14183).

A north-north-east lamprophyre dyke cuts across the Starav Granite-junction and is chilled against both granites in the bed of the River Kinglass. It differs petrologically from the dykes of the great north-north-east suite, in containing purple augite and in other characters (14189). This is the only dyke that can correspond to Mr. Kynaston's unique example of a porphyrite dyke cutting the Starav mass. A 'porphyrite' dyke has indeed been mapped farther up Glen Kinglass within the Starav Granite, but this is really a pegmatite. The few dykes found in the heart of the Starav mass trend north-west and south-east, and are petrologically quite distinct from the rocks under description (for instance, 7762 is a camptonite). Thus, not a single normal member of the north-north-east suite of dykes cuts the Starav Granite, while a considerable number have undergone contact-alteration in its immediate neighbourhood.

Special visits were paid to the sections on Beinn Sguliaird and in Glen Dochard, quoted by Mr. Kynaston as showing a passage for a short space between the Cruachan and Starav Granites. In the clearest sections here we found a sharp line between the two intrusions, but in weathered, lichen- and moss-covered crags it is frequently difficult to locate the exact junction.

An example of granitic intrusion belonging actually to the dyke period is afforded by a band of aplitic composition, which has been traced between Meall Odhar and Stob Ban on the south side of Glen Etive. It cuts some of the north-north-easterly porphyrite dykes, although it is intersected by others. The boundaries of this intrusion have been inserted on the general map (Pl. XXXIV).

Fig. 3.—*Porphyrite dyke traversing rhyolites at the foot of the northern front of the Buachaille Etive Beag (about $\frac{1}{30}$ nat. size).*



[The figure shows that the walls of the country-rock are counterparts, the one of the other.]

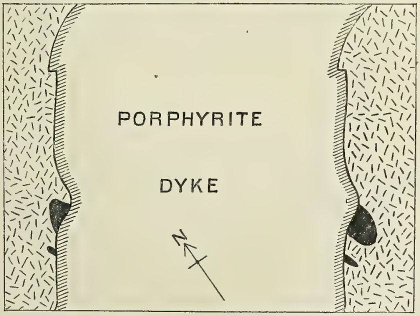
In our district, therefore, the main dyke-phase intervenes between the uprise of the Cruachan and Starav Granites, and is in part contemporaneous with the intrusion of the much smaller mass of Meall Odhar. Taking a more general view, we find similar dykes widely distributed both in the Highlands and in the Southern Uplands. The latest stratified formation which they ever traverse is the Lower Old Red Sandstone, as in Glen Coe; and in other districts they have yielded a profusion of pebbles to the Upper Old Red Sandstone conglomerates.

One of the dykes in Allt nan Gaoirean and several in the clean-washed section of Glen Dochard are intensely sheared in a direction which may make any angle up to 45° measured from the alignment of the dyke. The structure, like that which affects the early fault-intrusion of Allt Coire an Easain, has deformed the phenocrysts, especially the ferromagnesian minerals, which are drawn out into long lenticles. It is generally traceable right up to the dyke-margin, but is only doubtfully recognizable in the massive Cruachan Granite outside. After the shearing movements ceased, a certain amount of recrystallization has taken place, which may be due to contact-action by the Starav Granite, but the shearing itself may well be due to movements attending the introduction of the latter mass.—*October 22nd, 1909.*]

Besides, as it were, setting their seal upon Glen Coe, and thus establishing the fact that all its remarkable history of movement was accomplished in one long period of igneous activity, these dykes by their mode of intrusion bear witness to a redistribution of earth-stresses, which took place after all subsidence had ceased, and brought about an important modification of the original outline of the cauldron, amounting to an elongation normal to the direction of the dykes.

In many clear exposures the cheeks of the dykes are strictly parallel, and this parallelism is usually maintained, even in places where the dyke shifts itself laterally in its course. In the accompanying diagram (fig. 3, p. 642) of a porphyrite dyke traversing rhyolite at the foot of the northern front of the Buachaille Etive Beag, it will be seen that the cheeks of the dyke are counterparts the one of the other, and that if the material of the dyke could be removed, the walls of the country-rock might be closed up completely without any gap remaining. An apparent exception exists at the angle marked X, where the eastern wall bends in sharply in advance of the deflection of the opposite wall, in such a way that a gap would be left, if the walls of country-rock were fitted together again. But just at this point there floats in the dyke an inclusion of country-rock, the size and shape of which is such that it would exactly fill the gap. It should be remarked that the lateral displacement of the dyke is not due to cross-faulting, for the dark chilled border of the dyke-rock follows round all the irregularities of the margin, and even surrounds the inclusion. Hence we may conclude that the dyke-magma was intruded into a fissure, opening in the country-rock, and that no appreciable absorption of the latter took place.

Fig. 4.—*Porphyrite dyke traversing the Moor of Rannoch Granite in the bed of the River Etive, 500 yards above Kingshouse. (About $\frac{1}{24}$ nat. size.)*



[Complementary portions of two basic secretions in the granite are found on opposite sides of the dyke.]

This argument is clinched by an example taken from a dyke

intruded into the Rannoch Granite, and exposed in the River Etive 500 yards above Kingshouse. The granite contains dark basic secretions, ellipsoidal in shape, and rarely more than a foot in length. Two of these secretions are truncated at the margin of the dyke, and exactly opposite, on the further edge of the dyke, are found their complementary portions (fig. 4, p. 643). The size and shape of the separated parts of the secretions are such that there can be no doubt that the parts were united before the intrusion of the dyke. This example shows incidentally that the dyke was not intruded along a line of fault, an observation which may be verified again and again in the numerous cases of dykes intruded into the bedded volcanic rocks. Reference has already been made to the fact that dykes occasionally follow pre-existing fault-lines, but we cannot point to any case in which the intrusion of a dyke was accompanied by faulting.

It is clear then that the dykes of Glen Coe are not associated with phenomena of faulting or absorption of the country-rock, but that their thickness is a definite addition to the cross-section of the district which they traverse, The fissures which they occupy are, perhaps, merely widened joints. for the volcanic rocks are traversed by two sets of joints, one of which trends north-north-east and south-south-west, while the other runs at right angles to this direction. It is important to notice in this connexion that the joints, like the dykes, run in parallel lines, and maintain their general verticality even where they pass through the tilted or overturned volcanic rocks on the margin of the cauldron. Further, in areas in which the dykes are inclined away from the vertical, as in the neighbourhood of Alltchaorunn, the chief joints are also inclined in the same direction and to about the same extent as the dykes.

From the facts enumerated above we may conclude that the period following on the final subsidence in the cauldron was marked by the formation of a vertical, or nearly vertical, series of joints. Subsequently, certain of the joints, trending north-north-east and south-south-west, were opened and injected with molten material under conditions of relative tension in the rocks traversed by the dykes. This process of intrusion must have taken place intermittently, for composite dykes, in which a later dyke has been intruded along the central line or the margin of a previous one, are not uncommon in the district.

The tensional stresses, which, co-operating with the hydrostatic pressure of the magma, opened the joints and admitted the dykes, must have acted in a direction normal to that taken by these intrusions. The amount of stretching, or rather the displacement of two points at opposite ends of the district, might be measured by the sum of the widths of the dykes. On enquiring into this matter in detail, it was found from examination of the section of the River Etive, a little above Alltchaorunn, that in a distance of 1133 yards,

measured at right angles to the general trend of the dykes, the sum of the widths of 31 dykes amounts to about 335 yards. Assuming this to be an average for the district, the amount of stretching in a space of 9 miles, which is the length of the cauldron measured across the direction of the dykes, is no less than 4683 yards, or over $2\frac{1}{2}$ miles. While it can hardly be more than a coincidence that the greatest diameter of the cauldron lies normal to the trend of the dykes, that is, in the direction of the virtual tension which admitted them, still it is evident that, at the time of its formation, the cauldron was distinctly more circular in form than it is now.

We may now proceed to call attention to some important points relating to the distribution of the dykes. They are most numerous in the volcanic area itself, and their numbers diminish somewhat rapidly both south-eastwards and north-westwards; in fact, at a distance of 3 miles from the nearest outcrop of the volcanic rocks, measured across the direction of the dykes, only a few isolated occurrences of the latter are found. On the other hand, they pass north-north-eastwards in the direction of their alignment in great numbers; they cross the River Leven 3 miles north of Glen Coe, without any marked diminution, and in this direction the limit of their extension has not yet been determined. On the other, or south-south-western side of the cauldron, they enter the Cruachan or outer ring of the Etive granite-complex, as already frequently remarked, but they rapidly decrease in number as they approach the margin of the central mass of the Starav Granite.[1]

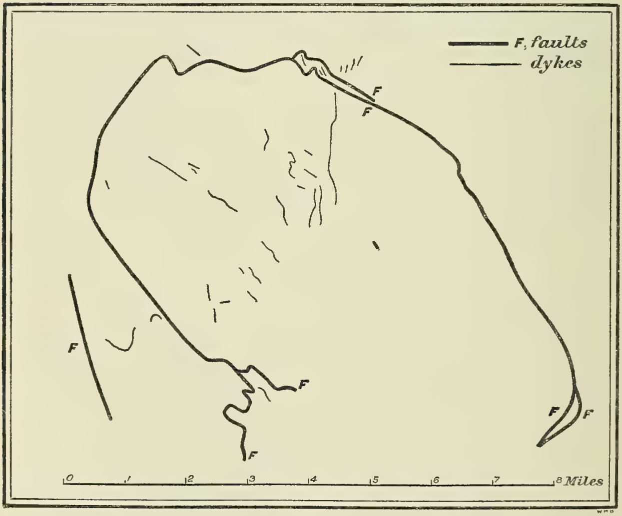
If observation were restricted to this side of the Etive boss it might be supposed, perhaps, that the dykes had some essential connexion with the Glen Coe volcanic area, but a wider view of their distribution shows that the connexion is less direct than might have been supposed. It is well known that a great series of dykes, similar in composition and orientation to those of Glen Coe, have been mapped by Mr. Kynaston in the southern part of the Cruachan Granite ring. From the granite they stretch in a south-south-westerly direction across the volcanic plateau of Lorne, and beyond this into Craignish and Kilmartin, a distance of nearly 25 miles from the margin of the Etive Granite, while a few stragglers may be found even farther south still. These two swarms of dykes, similar to one another in composition, trend, and geological age, are thus seen to possess a distribution which is symmetrical with regard to the Etive Granite. On referring to fig. 1 (p. 614), it will be seen that the breadth of the tract infested by the Lorne group of dykes is practically the same as that infested by the Glen Coe group. Further, it is significant that both these tracts are included between two lines which are parallel to the

[1] Later examination has rendered this decrease doubtful. See footnote, p. 641.

alignment of the dykes, and are also tangential to the margin of the Etive Granite. Outside these lines only a few sporadic dykes are found; these stragglers, however, maintain the normal north-north-east and south-south-west direction, and afford no indication whatever of a tendency to radial grouping. We may draw the conclusion, therefore, with some confidence, that the abundance of the north-north-east dykes in Glen Coe is little more than a coincidence, and that these dykes have their focus in the heart of the Etive Granite.

A suggestion as to the relationship of the dyke-swarms to this focus will be made in the theoretical discussion at the end of this paper (p. 673).

Fig. 5.—*Map showing the distribution of the local dykes of Glen Coe.*



In addition to the great swarm of north-north-east dykes in Glen Coe there are a few which are of earlier date. They have a local distribution, and obviously are closely connected with the Glen Coe centre (fig. 5).

They are often of lava types and follow no common direction. They are also invariably cut by the north-north-east porphyrite dykes. Definite evidence of the early date of several felsites

belonging to this group is forthcoming along the northern front of the subsidence, where it will be shown in the detailed descriptions that:

(1) Their surface-distribution bears somewhat the same peripheral relation to the sunken area as that of the fault-intrusions (pp. 653–55);
(2) In some cases they aim at the early fault-intrusion of the district, without ever cutting it (p. 655);
(3) They have been sheared locally, like the early fault-intrusion (pp. 653, 656); and
(4) The pink porphyrite of the fault-intrusion proper is, in Meall Dearg, clearly chilled against a typical member of the series (p. 659).

It is believed, however, that while there were several early volcanic felsite dykes, there were also later dykes of the same type belonging to a period later than the fault-intrusion. Thus north of Garbh Bheinn, felsite dykes are known which sometimes adopt the normal north-north-east direction of the great porphyrite suite; but they are few in number, and all of them are of earlier date than the porphyrites of the same neighbourhood.

The majority of the local dykes are of quartz-porphyry or hornblende-andesite, and are intruded into the lavas within the cauldron-subsidence. They are older than the north-north-east dykes, and they have not been found cutting the fault-intrusion or the Cruachan Granite. It is impossible, therefore, to fix their precise age, but it is clear that they belong to the Glen Coe centre.

Lastly, we may mention certain early hypabyssal intrusions, occurring in the district, but not obviously connected with the Glen Coe centre. These are horizontal sheets of vogesite, always cut across by the porphyrite dykes, and never found intrusive into the lavas and granites, although in the schists they are widely distributed. In addition to this, numerous blocks, almost certainly derived from one of these sheets, have been found enclosed in an intrusion-breccia with fault-porphyrite matrix, exposed in a stream-bed west of Garbh Bheinn. It appears fairly certain therefore that these vogesite sheets are the earliest manifestation of igneous activity occurring in the Glen Coe district.

(*b*) Special Description of Selected Sections.

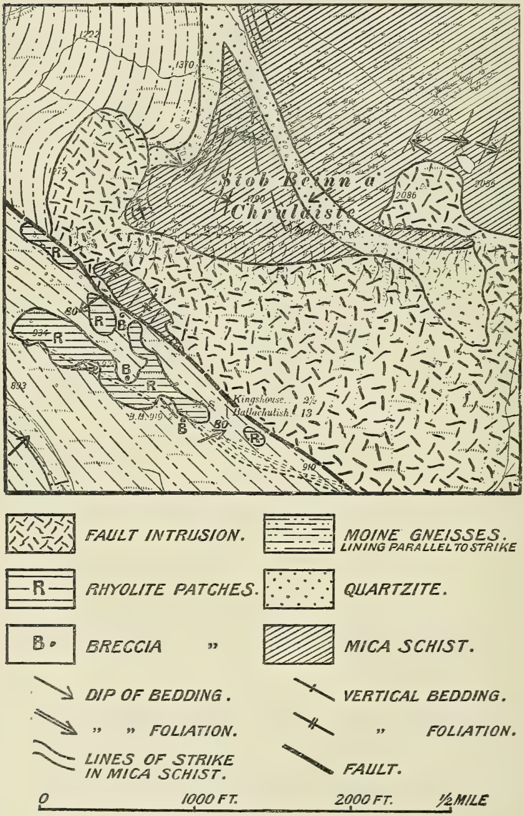
A general account has now been given of the marginal phenomena of the Glen Coe subsidence. We may next consider a few sections along the line of the boundary-fault, which seem to require further illustration.

Stob Beinn a' Chrùlaiste.—Sufficient has been said already on the direct evidence for the faulting observed on each side of Allt Coire an Easain, and again at Meall a' Bhuiridh and in the Cam Ghleann. Further, it has been pointed out that the fault-intrusion, linking these localities together and uniting them with Stob Beinn a' Chrùlaiste on the north, speaks for the continuity of the boundary-fault in this ill-exposed eastern portion of the district.

On the slopes of Stob Beinn a' Chrùlaiste itself, although morainic drift still obscures much of the geology, the position of the fault

Fig. 6.—*Map of Stob Beinn a' Chrùlaiste (north-north-east dykes omitted).*

[Based upon the Ordnance Survey Map, with the sanction of the Controller of H.M. Stationery Office.]

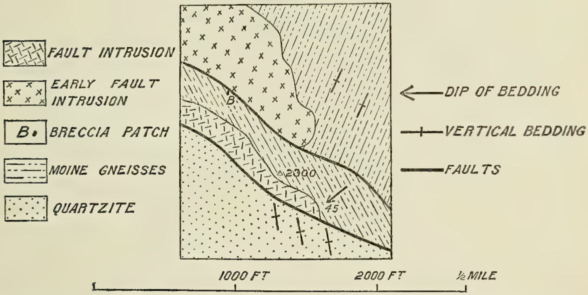


can once more be ascertained with certainty. For a short space, indeed, as may be seen from the sketch-map (fig. 6), the fault-line serves as the boundary between mica-schist striking north-north-east and quartzose 'Moine' gneisses striking north-west. With the latter occur scattered outcrops of pale grey lavaform rhyolite associated with patches of sedimentary-looking breccia, both of which appear to be restricted to the southern side of the fault. The northern side is the home of the fault-intrusion, which, at one point, extends in a tongue along the dislocation, and is clearly chilled against an outcrop of the rhyolite.

No appearance of special shearing has been noticed in the vicinity of the fault-line in this Stob Beinn a' Chrùlaiste section, but it must be remembered that much of the ground is very obscure.

Stob Mhic Mhartuin (fig. 7).—For a mile west of Stob Beinn a' Chrùlaiste the country is too thickly littered with moraines

Fig. 7.—*Map of Stob Mhic Mhartuin (north-north-east dykes omitted).*



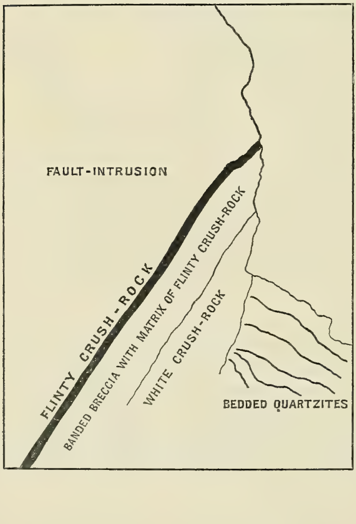
to furnish evidence regarding the boundary-fault. In Stob Mhic Mhartuin, however, the complex features of this disturbance are illustrated with a clearness which is almost diagrammatic. This hill makes a prominent feature near General Wade's military road, where the latter follows the zigzag ascent out of Glen Coe known as The Devil's Staircase; and the section is easy of access, since a grassy slope leads up to it from the main road on the floor of the Glen.

The rocks at the foot of the low frontal cliff of the Stob, that is, on the southern or inner margin of the boundary-fault, are well-bedded quartzites. They are vertical, and have a uniform north-north-westerly strike, like the other schists of the neighbourhood within the faulted area. Preliminary signs of trouble, however, are not wanting. Several narrow zones of shearing are encountered crossing the quartzite in a west-north-westerly direction,

before the main line of fault is reached. The crush-rock occupying these minor planes of movement generally measures a few inches across, and has a poorly developed platy structure parallel to its edges; as a rule, it is so finely ground, that to the naked eye it shows very little evidence of brecciation. The strike of the quartzite is sometimes sharply deflected in the immediate vicinity of these shear-bands; but sometimes, on the other hand, it is quite abruptly truncated. Although the crush-rock has in all these cases lost every sign of bedding, it is still white and its quartzitic nature is obvious.

On approaching the main line of movement, the quartzite is again torn out in the manner just described; and a belt is formed of white, crushed, quartzitic rock a couple of feet thick (12329). Beyond this, long tongues of the white rock begin to be isolated in a darker matrix, and in the next stage disintegrate, while the proportion of matrix rapidly increases. The latter possesses an obvious flow-structure which winds round the abundant inclusions, in much the same manner as the banding in the flow-breccias so often found among the rhyolite lavas. Movement has apparently been so intense in this case as to lead to incipient fusion (p. 629). This breccia with flow-banded matrix is a foot wide, and next to it comes the flinty crush-rock (12332), the extreme product of the disturbance (fig. 8.)

Fig. 8.—*Diagram of the boundary-fault, as seen in the cliff of Stob Mhic Mhartuin.*



The last-mentioned rock is only an inch thick. It is most delicately banded; and, though it sometimes weathers with a light-coloured crust, when freshly fractured it is quite black, and possesses a semi-vitreous lustre. The only fragments visible in it are minute gleaming specks of quartz, which occur in great numbers and are easily discernible with a pocket-lens, as also a few tiny crystals of pink felspar, which are found for the most part close to the junction with the fault-intrusion to the north.

All these different zones of crush-rock, with their platy structures and flow-banding,

are inclined at 70° towards the north-north-east: the fault in this locality is, therefore, distinctly reversed. The same feature is characteristic of the dislocation in the Cam Ghleann, where the inclination is again 70° in a north-easterly direction, and a reversed hade is also found along much, if not the whole, of the northern front of the subsidence.

Next to the flinty crush-rock, and obviously chilled against it, rises the broad dyke-like mass of fault-intrusion, which forms the prominent little cliff of the Stob. The rock here is a typical example of the coarse grey porphyrite type of the intrusion. For the most part the chilled edge of the porphyrite follows the flow-banding of the flinty crush-rock; but, at one point,[1] it cuts across this banding for a fraction of an inch, and isolates minute angular fragments of the flinty crush-rock. Obviously then, the latter rock, at this point, was solid when the porphyrite was still liquid. But one need not conclude from this that the flinty crush-rock was solid at the time of the upwelling of the fault-intrusion. On the contrary, the small and frequently broken felspar crystals, enclosed in the crush-rock, point to the continuance of viscous flow in the latter after it had come into contact with some portion of the fault-intrusion, for the felspars are almost certainly xenocrysts derived from this intrusion.

The dyke-like mass of the fault-intrusion forming Stob Mhic Mhartuin is about 30 yards wide. After crossing it, we pass on to quartzose schists striking south-east, a direction distinctly different from the south-south-easterly strike of the quartzites on the south (fig. 7, p. 649). Moreover, some of the beds here are inclined at angles no greater than 40°: a marked discordance, therefore, exists between the arrangement of the schists on the two sides of the great line of flinty crush. The quartzose schists, too, are not merely the twisted continuations of the quartzites already described: for they are evidently more micaceous, and have been correlated, though with some hesitation, with the Moine Group to which reference has been made. They show signs of an irregular shearing altogether later than their foliation, and also of reddening; the latter feature, however, is not strongly accentuated.

When about 80 yards of these schists have been passed over, another important line of movement is encountered running west-north-west, parallel to the first. It has the same distinguishing characteristics, for the schists on approaching it become thoroughly sheared and pass into a narrow ribbon of flinty crush-rock. Chilled against this, as before, we find a broad dyke-like mass of porphyrite. This is the early fault-intrusion already described at some length. Not only is it chilled against the fault-line, which it borders, but it has frequently suffered, both along its margin and in its interior, from a recrudescence of shearing posterior to its consolidation. The

[1] Geologists who may visit this section are asked to do no injury to this exposure.

difference between the moved and the unmoved portions of the rock are quite striking on weathered surfaces. The normal rock [1] yields big blocks evenly bounded by joint-planes, and smooth except for a conspicuous pitting due to the weathering out of the phenocrysts. In an early stage, movement manifests itself by the production of a closely interlacing meshwork of cracks, weathering white on the grey face of the rock. Further movement causes obvious displacement along these cracks, and the breaking-down of the phenocrysts leads to the disappearance of the characteristic pitting; the rock no longer weathers in flat-faced blocks, but with a rounded, uneven surface, recalling somewhat in appearance the grey lichen-covered trunk of an old beech. Along special bands of shear, streaks of flinty crush-rock have frequently been induced, which show up black on a fractured face (12933).

The occurrence of these isolated flinty crush-bands, evidently produced *in situ*, is of importance as dispelling the idea that the formation of this type of crush-rock has any essential connexion with igneous intrusion. The independent dynamic origin of flinty crush-rocks has, of course, been clearly recognized in all districts where rocks of this type have been studied; but it is extremely satisfactory to find clear local evidence bearing upon the point.

Beyond the outcrop of the early fault-intrusion, we pass on to schists which attest that the line of movement, recognized along the southern boundary of the intrusion, is one of great importance. Here, on the northern flank of Stob Mhic Mhartuin, the strike is south-south-west, and the strata are practically vertical. They consist of quartzo-micaceous granulitic flagstones, which certainly must be placed in the Moine Group of the Central Highland Schists.

For some distance these schists, or gneisses as they are more properly termed, show signs of movement, incipient and occasionally complete brecciation, and also of local reddening. These effects do not extend for more than about a third of a mile from the belt of maximum disturbance, and evidently are connected directly with the movements of subsidence which have affected the Glen Coe area.

Lastly, it may be mentioned that the normal north-north-east porphyrite dykes of the district traverse Stob Mhic Mhartuin in great number. They cross all the zones of disturbance without themselves showing any signs of trouble, and they exhibit chilled margins at their contacts with the two fault-intrusions which they traverse without let or hindrance.

The Stob Mhic Mhartuin section has been dealt with fully, because it presents an epitome of many of the more important features of the Glen Coe boundary-fault. It is fortunate that in this readily accessible section there should be such clear evidence of two definite stages in the Glen Coe subsidence.

[1] 'The Stob Mhic Mhartuin section does not give so good an idea of the unmoved rock as others lying to the west.

Coire Odhar-mhòr (fig. 9, p. 654).—West of Stob Mhic Mhartuin, exposures are poor until Sron a' Choire Odhar-bhig is reached. On the face of this ridge looking down into Coire Odhar-mhòr, the two lines of flinty crush met with in Stob Mhic Mhartuin are again well exposed. The southern one is smashed by a later movement following the old line of weakness and shattering even the north-north-east porphyrite dykes. The grey porphyrite, representing the fault-intrusion, occupies, at this point, the whole distance between the two planes of movement. On the north it exhibits a chilled undisturbed edge against a banded flinty crush-rock, which on its other side passes imperceptibly into the strongly sheared margin of the early fault-intrusion. This is, it will be remembered, the type section for illustrating the difference of age of the two fault-intrusions. It is also interesting, as having furnished a specimen of flinty crush-rock containing numerous well-defined margarites and longulites (12934).

The map shows clearly the steep uptilting of the lavas away from the boundary-fault. It also indicates the position of the small patch of breccia, situated between the two branches of the fault, which has been discussed already on p. 626. A little north of this apparently sedimentary breccia, stands a crag of quartzite which also shows signs of brecciation, but of a kind that one can readily refer to dynamic agencies. The great interest of this crag lies in the fact that it is traversed by several irregular veins of flinty crush-rock, which wind through it like so many intrusions of felsite. These veins (12333 and 13929) consist of typical, banded, black flinty crush-rock, spangled with specks of quartz, just as are the flinty crush-rocks of Stob Mhic Mhartuin. But these veins were not manufactured *in situ*. There is no shearing of the country-rock parallel to their margins, nor is there any regularity in the course which they follow; in fact, in many cases they extend as tongues, entering culs de sac in the quartzite, and everywhere exhibiting a delicate flow-banding which accurately conforms with the intricacies of the margin. Clearly in this case the flinty crush-rock has been injected as a fluid away from its source of origin. Just as Stob Mhic Mhartuin, then, furnishes the most convincing evidence of the mode of formation of this curious rock, so does the crag in Coire Odhar-mhòr prove conclusively its fluidity.

One of these veins of flinty crush-rock traverses, not only the quartzite but also a small intrusion of pink felsite, thus indicating the existence of 'early' felsites in this locality. As a matter of fact there is good evidence for assigning a whole suite of such intrusions to some early epoch in the development of the cauldron-subsidence. They occur in the form of short irregular dykes and are always cut across by the north-north-easterly porphyrites. They are extremely abundant in this neighbourhood (a few only have been picked out on the map), and, what is especially significant, they have precisely the same distribution in the field as the

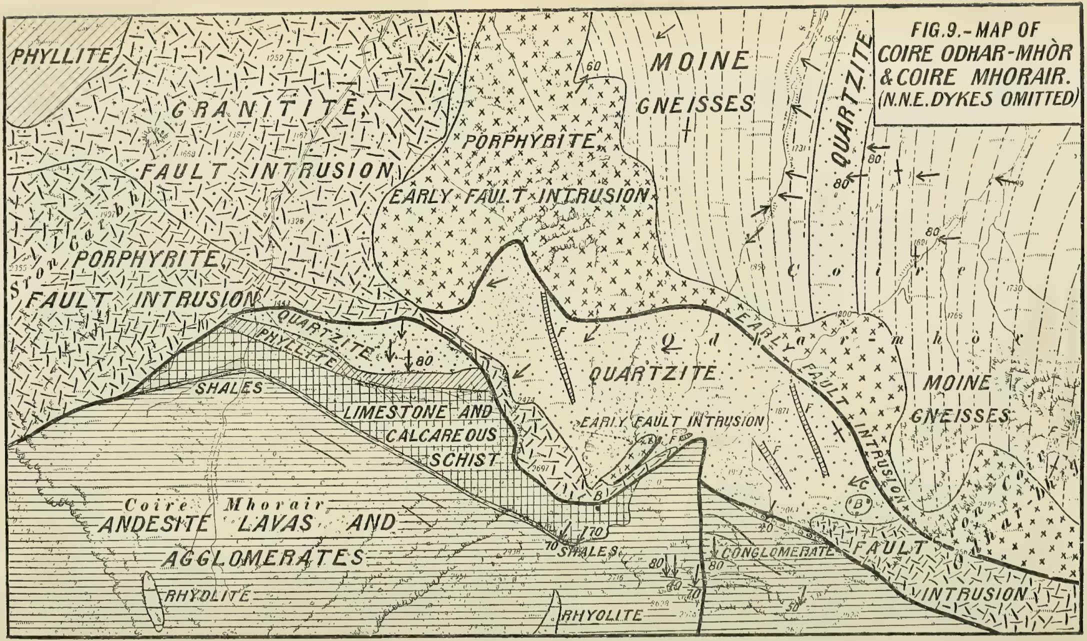


FIG. 9.—MAP OF COIRE ODHAR-MHÒR & COIRE MHORAIR. (N.N.E. DYKES OMITTED)

F,=EARLY FELSITE DYKES; • B,=BRECCIA PATCHES; C,=INTRUSIVE FLINTY CRUSH-ROCK.
→ DIP OF BEDDING; ┼ VERTICAL BEDDING; /LINES OF OUTCROP; —— FAULTS

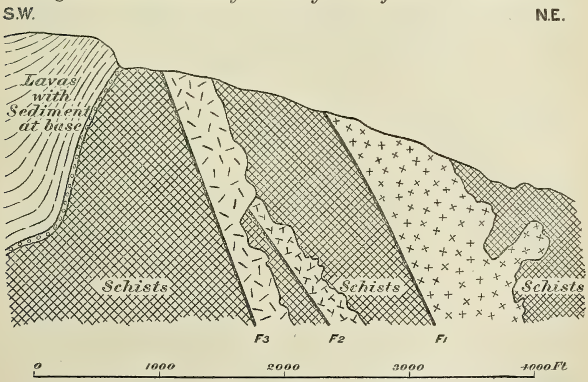
0 1000 FT 2000 FT 3000 FT 1MILE

[Based upon the Ordnance Survey Map, with the sanction of the Controller of H.M. Stationery Office.]

reddening of the schists. Like the latter phenomenon, they are not found within the circumference of the inner fault, nor do they extend far beyond that of the outer one. They are probably older than even the early fault-intrusion: for they do not cut the latter, although it crosses the zone of their maximum development.

Proceeding west-north-westwards from Sron a' Choire Odhar-bhig, we may follow the line of the older fault to the point where it is finally lost sight of. It presents no special point of interest, until the slope is reached looking down into Coire Mhorair. The flinty crush, affecting both schist and early fault-intrusion, is well exposed here, and the fault-plane overhangs, having a northerly inclination of 70° measured from the horizontal (F_1 of fig. 10). The old line of movement has been followed, as is so often the case, by later shattering. Half way down the hill-slope a sudden change occurs in the direction of the porphyrite margin, and presumably also of the fault itself. The former is seen to turn sharply through a right angle; and, instead of being inclined at 70° north-north-eastwards, it now dips north-north-westwards at about the same angle. The bend must be very abrupt, but it is obscured somewhat by later crushing.

Fig. 10.—*Section through the ridge west of Coire Odhar-mhòr.*



[F_1 & F_2=Early faults, accompanied by fault-intrusions; F_3=Main fault with fault-intrusion.]

Returning to Sron a' Choire Odhar-bhig, it is an easy matter to trace the inner branch of the fault westwards into Coire Odhar-mhòr. Here it makes two short but sudden bends recalling the one just described in the older fault: the sections, however, are not quite so clear.

Ascending the slope on the western side of Coire Odhar-mhòr, the fault obviously overhangs (F_3 in fig. 10), and is accompanied

along its outer margin by a dyke of typical fault-porphyrite. On the lower slopes at this point it is flanked on the north by a branch fault (F_2), accompanied in turn by a grey porphyrite. This rock is very similar to, but scarcely identical with, the early fault-intrusion already described farther to the north. Like the latter it has suffered locally from shearing, and near the top of the slope it is cut across obliquely by the fault-intrusion proper. A sheared felsite (not shown in the section) occupies the angle between the two intrusions; probably it is one of the early felsite dykes already referred to. Farther down the slope of the hill a felsite or rhyolite dyke, which may, however, be of later date, appears to accompany the inner fault-line. There is perhaps no more complicated bit of ground in the district. At the same time, the lesson to be learnt from it is the old one of repeated movement and intrusion along the margin of the Glen Coe subsidence.

Standing upon the ridge between Coire Odhar-mhòr and Coire Mhorair, the observer may at first be bewildered by the profusion of later north-north-easterly porphyrite dykes. But the fault-porphyrite itself is quite distinct, both in character and in texture, from these intrusions; and its outcrop, running at right angles to their direction, is a clear indication of the position of the fault, which on the slopes beyond is again marked by later shattering. The difference between the Schists on each side of the fault-line, exposed on this ridge and in the corries to the north and south, is very striking: inside the fault, pure white quartzites dip steeply beneath thin phyllites and black slates, and these under calcareous schists and limestones; outside all is quartzite or quartzitic schist. The strike is different in the two cases, but what first attracts attention is the contrast in the condition of the rocks on each side of the disturbance. The bedding of the Schists lying to the north is often obscure, and local reddening is sometimes extremely well marked. In addition to this, as already stated, the Schists are crossed by abundant irregular intrusions of pink felsite, which are quite unknown on the downthrow side of the fault, either in the volcanic rocks or in the schists which underlie them.

Meall Dearg and Coire Càm.—The fault can be traced, coinciding with the inner margin of the fault-intrusion, from Coire Mhorair along the watershed to the south of Sron Garbh. Its steep descent into Coire nan Lab, farther west, is also clearly marked by the smooth, chilled, and shattered edge of this intrusion. In the floor of Coire nan Lab the fault is lost sight of for a short space, but it soon reappears and ascends the Meall Dearg ridge beyond; here it once more overhangs markedly, being inclined at about 50° to the horizontal. Immediately south of the summit of Meall Dearg, considerable masses of quartzite occur, almost surrounded by the fault intrusion, but at the same time brought into contact with the Old Red Sandstone lavas along the line of dislocation (fig. 11, p. 658).

The fault is splendidly exposed in the precipitous western slopes of Meall Dearg. It overhangs just as conspicuously here as it does on the other side of the ridge, and the lavas in its vicinity are steeply reversed; and in one locality, as already described, the basal conglomerates and the old schist-floor are also brought to light in a similar inverted position.

In Coire Càm the fault performs the most striking of its many changes of direction; whereas it descends into the corrie from Meall Dearg with an east-and-west trend and a northerly inclination of about 50°, it ascends Aonach Eagach with a south-west strike, and so steeply inclined as to be practically vertical. The precise position of this sudden bend is unfortunately not exposed.

North of Aonach Eagach the fault which now runs south-westwards is marked by shattering, and also by the omission of the basement conglomerate of the Volcanic Series; the lavas are here thrown directly against the quartzite outside, and along the summit of Aonach Eagach they assume a vertical position near the disturbance. South of this ridge the fault is equally clear, for it throws phyllites, to the east, against quartzites, to the west. At intervals along the line from Coire Càm to the bottom of Glen Coe, the fault has been followed by a dyke of xenolithic rhyolite, sometimes as much as 50 yards in width. This greatly resembles in appearance many of the lavas of the sunken area, and is earlier than the porphyrite dykes with which it comes into contact; its age, in relation to the fault-intrusion, however, has not been determined.

The manner in which the zone infested by the fault-intrusion follows the same abrupt bend as the fault itself, is best appreciated by a glance at the general map. The alteration due to this suite of intrusions is almost completely limited to the outside of the fault-line. Both these points have been dealt with already, and so we are now free to pass on to the consideration of another aspect of the mode of occurrence of the fault-intrusion, which has not yet received attention. Many of the minor masses of this intrusion are obviously laccolitic in nature. In fact, a good example of a small laccolite with neatly arched roof is a conspicuous feature on the northern slope of Glen Coe, above Clachaig. From this it is probable that some of the larger masses may also be of laccolitic form. It can at any rate be shown, conclusively enough, that the large body of porphyrite forming the Meall Dearg ridge has a comparatively flat and even base. Away from the fault the margin of this intrusive mass follows an approximately level course on both sides of the ridge. The main outcrop of the porphyrite stretches in this manner for a mile north-east from the fault; but, about half way along its course, it is completely severed by an important felsite dyke, although, strange to say, the latter is the older rock: in fact, the fault-porphyrite is clearly chilled, at one point, against the felsite dyke which interrupts its continuity (fig. 11, p. 658).

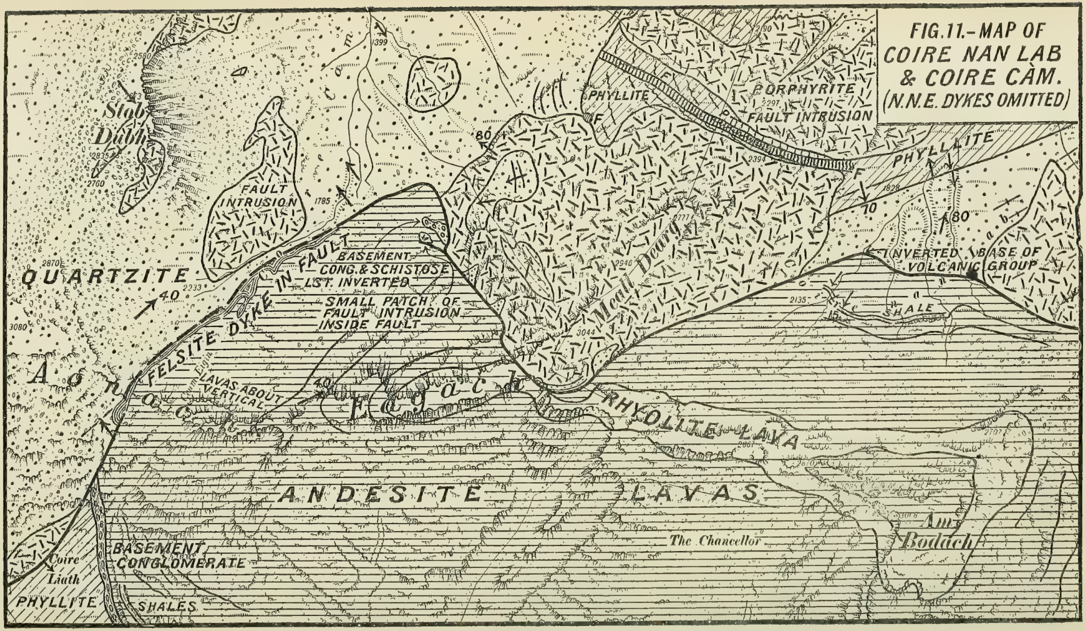


FIG. 11.—MAP OF COIRE NAN LAB & COIRE CÀM. (N.N.E. DYKES OMITTED)

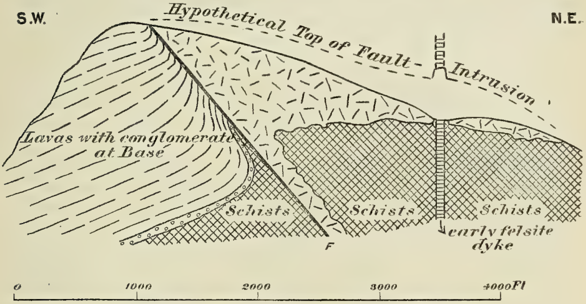
F = EARLY FELSITE DYKES; P = EARLY PORPHYRITE DYKES;
→ DIP OF BEDDING; + VERTICAL BEDDING; LINES OF OUTCROP; — FAULT.

0 | 1000 FT. | 2000 FT. | 3000 FT. | 1 MILE

[Based upon the Ordnance Survey Map, with the sanction of the Controller of H.M. Stationery Office.]

This dyke is about 50 yards wide, and runs nearly east and west. As a rule, it is flanked on each side by a thin strip of phyllite, but a foot or two broad[1]; and it is, of course, only where the fault-porphyrite has broken through this border of phyllite, and has reached the felsite within, that it exhibits a chilled margin against the latter. This curious relationship appears incomprehensible, unless we suppose that the Meall Dearg intrusion has a flat base: on such a supposition the interpretation is not difficult. It seems

Fig. 12.—*Section through Meall Dearg.*



[F=Fault, accompanied by fault-intrusion.]

probable that the fault-intrusion spread outwards in the form of a more or less horizontal sheet, and that the felsite dyke, with an adherent coat of hardened phyllite, fractured, so as to give room for this sheet, at a slightly higher level than the country-rock on each side. Hence the dyke now projects as a low bar above the general level of the floor of the later intrusion (fig. 12).

Dalness and Beinn Ceitlein.—The features of the fault between Glen Coe and Glen Etive have been so frequently referred to in the foregoing pages that they require no further illustration. There are two branches: the inner one, in Gleann Fhaolain, serves as the boundary-fault of the volcanic rocks; the outer one, in Gleann Chàrnan, is equally clearly revealed by its effect upon the outcrops of the Schists. In both cases the fault-intrusion extends along the outer margin of the dislocation. The inner fault can be shown, in more than one place along its course, to have a normal inclination of about 70° towards the area of subsidence.

On the south side of the Etive the inner fault is well seen on the hillside, about 1100 yards south-east of Dalness. It inclines

[1] For some distance there is also a flanking porphyrite dyke, older than the felsite.

in this locality steeply north-east, towards the subsidence, and separates quartzite on the south-west side from altered breccias and ashy sandstones on the north-east. These breccias and sandstones belong to a group which in this district comes between the andesitic lavas of group 1 and the rhyolitic rocks of group 2. They are separated from the quartzite on the south-west by a highly sheared band, partly made up of igneous rocks ; and also by a dyke of porphyrite, which leaves its usual north-north-easterly direction and runs south-eastwards along the fault for more than 50 yards. It is quite free from crushing, and is not far distant from other dykes which go without deflection through the fault.

About 100 yards farther south-east the rhyolitic rocks of group 2 are found in contact with the quartzite, without any intervening intrusive rock. Close to the junction they are crossed by various nearly vertical planes of shear, and by thin streaks of black flinty crush-rock. The flinty rock in a specimen (11464) which was obtained in this locality shows under the microscope incipient crystallization.

A little farther up the hill a fault-porphyrite, for the most part of a grey colour, comes in between the quartzite and the volcanic rhyolitic rocks of group 2, and it can be traced along or near the fault for about a third of a mile. Its north-eastern margin is distinctly chilled and nearly straight; and, for a little distance off, the bedding of the rhyolitic rocks appears to be nearly vertical, though 300 or 400 yards away it is approximately horizontal. The south-western side of the porphyrite is less regular than the north-eastern, and sends out various processes in a south-south-westerly direction, which are hard to distinguish from some of the common dykes of the neighbourhood. It is crossed, however, by a broad dyke of quartz-felsite, which is, in turn, cut by several dykes of porphyrite.

The ground farther south-east near the hilltop, just before the Cruachan Granite is reached, is obscure. In this tract the fault seems to be represented by at least three branches; but the two lying farther to the south-east are probably of no great importance. The main mass of the fault-porphyrite goes off to the south-west before the Cruachan Granite is reached. It is not clear that any portion of this granite penetrates along the fault.

On the west side of Beinn Ceitlein another important dislocation has been detected, which resembles the inner fault in being frequently accompanied by fault-porphyrite, and in being of earlier date than the north-north-easterly dykes. It is, however, generally less steeply inclined than the inner fault, and is more variable in direction of inclination and of outcrop.

On the hillside, about 680 yards north-east of the summit of Stob Dubh, it is unaccompanied by any fault-porphyrite, and is represented by a thin fracture-plane, no thicker than a knife-blade, which might be taken for a mere joint-plane were it not for the evident discordance between the Schists on the two sides. The

general inclination of the plane in this locality is slightly north of west at about 47°; and the rock above the plane, that is, on the south-west side of the outcrop of the latter, consists of garnetiferous mica-schist, while that below is quartzite.

From the locality just mentioned the fault continues in a south-easterly direction for about a quarter of a mile, and then turns and runs southwards for nearly the same distance. Farther south still, a broad mass of pink porphyrite has come up along the fault, and continues southwards until the granitic rocks are reached. The portion of the fault-line, so far described, which is free from fault-porphyrite, is nearly half a mile in length; but near the middle it is occupied or closely accompanied by a thin porphyrite dyke which locally gives up its usual north-north-easterly direction and proceeds along the fault for about 170 yards.

The same line of fault is seen again without any fault-porphyrite, on the hillside nearly 1000 yards north-east of Stob Dubh. At this spot it inclines northwards at about 28°, and separates the underlying quartzite on the south side from the garnetiferous mica-schist on the north. Thence it continues in a north-easterly direction for about a third of a mile, forming a distinct boundary all the way between the two Schists just alluded to. Its path farther northwards is not so clear, chiefly owing to the abundance of intrusive igneous rock, including both fault-porphyrite and also a considerable amount of quartz-felsite, part of which is older than the fault-porphyrite. In this direction, however, it is plain that the fault under consideration must be approaching near to the inner fault already described.

IV. General Conclusions and Discussion.

A brief summary has already been given (pp. 623, 624) of our main conclusions based upon a study of the volcanic succession in Glen Coe, its associated sediments, and its relations to the uneven, eroded floor of Schists beneath. General and detailed descriptions have followed, showing that:—

(1) The Glen Coe volcanic rocks occupy the major portion of a cauldron-subsidence, using this term in the sense in which it has been employed by Suess. The boundary-fault delimiting the cauldron encloses an area roughly oval in shape, and measuring 9 miles in length by 5 in breadth. The area within the fault has undergone extensive subsidence. Even near its edge the rocks have sunk well over 1000 feet, while the total displacement has been materially increased by sagging of the central parts.

One-fifth of the circumference of the cauldron is now obscured, it is true, by an offshoot of the Cruachan Granite, which has invaded the foundered area from the south, and obliterated the boundary-fault for a distance of about 4 miles. But it is obvious that this fault once completed its circuit, for the truncated ends of

the dislocation would meet one another in a perfectly natural manner if continued forward across the gap now occupied by granite.

(2) The movement of subsidence was of a somewhat unusual, probably very rapid type, as is indicated by the manufacture of a flinty crush-rock at some points, at least, along the line of dislocation. This flinty crush-rock owes its peculiar character to extreme trituration, with the probable accompaniment of incipient fusion, due to heat generated by friction in the plane of the fault.

(3) The boundary-fault, where it has not been obliterated by the Cruachan Granite, that is along four-fifths of its original extent, is surrounded by a discontinuous complex known as the fault-intrusion. This includes both granitic rocks and coarse porphyrites.

The inner boundary of the intrusion-zone is the boundary-fault of the cauldron, and is almost mathematically exact. In several notable instances large independent masses of the intrusion show smooth, clean-cut inner margins against the fault-plane, and ragged transgressive outer margins against the Schists beyond. Moreover, while the minor intrusions scattered through the zone outside the fault are innumerable, but three or four insignificant examples are to be found inside.

(4) Along its outer irregular margin, the fault-intrusion is sometimes obviously chilled and sometimes not; along its inner smooth margin against the fault-plane, it is invariably chilled. In like manner, the alteration induced by the fault-intrusion is almost entirely restricted to the zone external to the fault.

(5) There is clear proof that the cauldron-subsidence was not effected in a single stage. The evidence for this is best displayed on the northern margin of the cauldron, where an outer parallel branch of the fault of manifestly early date exists. Like its later companion, this early branch has its own special band of flinty crush-rock and its own special fault-intrusion. The latter, however, during the movements of subsidence connected with the production of the inner branch of the fault, has itself been sheared, and in many cases broken down, with the production of flinty crush-rock.

Another good example of an early branch of the fault, accompanied by an early fault-intrusion, presents itself on the east side of the cauldron. Here the older branch occupies the interior position.

(6) The fault-intrusion surrounding the Glen Coe cauldron is, in all probability, merely an offshoot from the Cruachan magma. The latter has penetrated the foundered area from the south, and underlies the lavas of the central district in which it causes contact-alteration. It cuts across lavas 2000 feet thick, without showing any indication of arching or tilting them. This lobe of the Cruachan Granite is confluent to the south with a much more extensive mass which, with its great core, consisting of the more acid

Starav Granite, forms a huge boss, 15 miles long and 10 miles broad. Collectively, the granitic complex of Cruachan and Starav is known as the Etive Granite.

(7) Between the periods of intrusion of the Cruachan and Starav granites intervened an important epoch marked by the injection of a great host of parallel north-north-easterly dykes (fig. 1, p. 614). For the most part they are porphyrites, and obviously closely related in composition to the granites.

The small aplitic granite strip traced north-westwards from Meall Odhar is certainly an intrusion dating from the general period of the dyke-phase. It is earlier than some of the dykes, later than others.

The dykes are 'regional' in their constancy of direction, for they exhibit not the slightest tendency to radial arrangement; but they are 'local' in their marked concentration into a definite belt with the Etive mass at its centre.

The dykes of this suite definitely add their own thickness to the width of the country which they traverse. Their injection has been accompanied by an opening of fissures in the country-rock and an outward displacement of the walls of these fissures; at the same time, it has not been accompanied by faulting.

(8) In addition to the dominant north-north-easterly porphyrite dykes, which are distinguished by their constant direction and wide distribution, there is in Glen Coe an earlier local set of dykes of irregular trend (fig. 5, p. 646). All these are cut by the north-north-easterly porphyrites and some of them can be shown to be of even earlier date than the fault-intrusion. They consist, for the most part, of volcanic types—andesites, rhyolites, and also felsites and quartz-porphyries.

A theoretical discussion of the results enumerated above may now be undertaken. Four main points will be dealt with:—

(*a*) The contemporaneity of the subsidence of the Glen Coe cauldron and the uprise of the marginal fault-intrusion.
This important matter will be examined first, in the light of the asymmetrical distribution of the fault-intrusion with respect to the boundary-fault, throughout the district as a whole; and secondly, in regard to its intimate relations with the flinty crush-rock, which is so well exposed in the typical section of Stob Mhic Mhartuin.

(*b*) A comparison between the Glen Coe cauldron of Old Red Sandstone age, and the modern Askja caldera, in Iceland.

(*c*) A suggestion as to the form and history of the Etive granite complex.

(*d*) The place of the dyke-phase of activity in the igneous phenomena of Etive and Glen Coe.

(*a*) The contemporaneity of faulting and intrusion.—The distribution of the fault-intrusion on each side of the boundary-fault is so strikingly asymmetrical, that we are bound to seek some element of asymmetry in the conditions which governed the intrusion.

Movement acting before, after, or during the period of intrusion appears to be the only possible cause of asymmetry admitted by the conditions of the problem.

Movement before the intrusion might lead to asymmetry by faulting down a relatively impenetrable type of rock on the inside of the cauldron-subsidence against a penetrable type on the outside. If, for instance, the whole of the foundered area were occupied, at the present surface, by lavas thrown against the schists outside, this explanation would appear extremely reasonable. But, as a matter of fact, the lavas have been so far removed by erosion that along half its course the boundary-fault is seen separating schist from schist. More than this, it is possible to recognize inside the cauldron the displaced equivalents of the very same members of the schist succession as occur outside. The asymmetrical distribution of the fault-intrusion is, therefore, not determined by any peculiar character of the down-faulted rocks; and accordingly it cannot be due to movement antedating the intrusion.

Faulting after intrusion might seem, at first sight, to account for the peculiarities of this distribution. Thus, if a consolidated igneous mass were to sink, roof and all, to a lower level, leaving merely its outer rim standing to mark its former presence, then denudation would eventually reveal a complex with much the same general appearance as that of Glen Coe. But faulting after the act is ruled out of court, in this case, for in a host of exposures the fault-intrusion is clearly chilled against the fault-plane. In some of these sections it is firmly soldered on to the fault-rock, having suffered no movement whatsoever since consolidation; and even in the more numerous instances where the junction has been shattered by later tremors following the old line of weakness, it has been so little moved that the thin chilled margin of the intrusion has not been displaced. Obviously, then, movement after the act cannot have determined the distribution of the fault-intrusion.

We are thus led to regard *the faulting and the intrusion as contemporaneous events*. They represent two aspects of a single adjustment. The magma welled up around the subsiding mass, like the liquor in a full bottle when the stopper settles home. The slowly rising stream found in the fault-plane its easiest avenue of escape. Thence, we may suppose, it tended to spread out symmetrically into the rocks on either side; but any portion which trespassed into the sinking mass was by a continuation of the subsidence carried down. Thus contemporaneous movement along the fault supplies the element of asymmetry which is the essence of the problem. It delayed the entrance of the intrusion into the downthrown mass, in comparison with the zone lying immediately outside. Within limits, this effect would certainly be cumulative, since each fresh invasion of the outer zone furnished an additional channel for the upward and outward movement of the ascending magma.

A surprising feature of the Glen Coe phenomena is the frequency

with which the fault-surface is found smooth and unbroken in contact with the fault-intrusion. This relation must be considered in connexion with the extraordinary number of xenoliths characteristic of the fault-intrusion. It seems probable that the magma advanced upwards largely by the process known as stoping.[1] Doubtless the solid schists were heavier than the ascending magma,[2] and accordingly tended to break off along their numerous structural planes of weakness and sink as fragments into the intrusion. But of all the planes of weakness, the fault-plane would be predominant, since, as has been seen, it was occupied by crushed material. Such a plane, it can readily be imagined, would tend to be stripped clean and bare when exposed to the operation of stoping, regulated by conditions strongly favouring asymmetry.

The argument so far employed relies upon the concordant testimony of several miles of section. It is, moreover, corroborated by the evidence which has been afforded by a detailed examination of the flinty crush-rock exposed at the foot of Stob Mhic Mhartuin (fig. 8, p. 650).

The flinty crush-rock here consists of finely ground-up quartzite and quartz-schist with a certain proportion of indeterminable base. It also contains, and this is the significant point, a few xenocrysts of felspar (13402, 13403) which are sometimes broken and have clearly been derived from the adjacent fault-intrusion. These xenocrysts are of about the same size as the smaller phenocrysts in the chilled margin of the intrusion, and some of them show well developed crystal-faces. Many are clear; but others, lying near the edge, are decomposed to the same extent as the phenocrysts in the intrusion. They seem, however, to have suffered more from fracturing and rounding than these phenocrysts, and often present a fragmental appearance. They may occasionally be found even half an inch in from the contact-zone, and separated from the latter by the uninterrupted flow-banding of their host. The position and fragmental nature of many of these xenocrysts proves that they have been involved in the viscous flow of the flinty crush-rock, and since they have certainly been derived from the fault-intrusion, it is manifest that viscous flow still continued in the flinty crush-rock after the arrival upon the scene of some portion of the fault-intrusion.

Doubtless the phenomenon just described was of strictly limited

[1] *Cf.* especially R. A. Daly, 'The Mechanics of Igneous Intrusion' 3rd paper, Am. Journ. Sci. ser. 4, vol. xxvi (1908) p. 17.

[2] Density of quartzite, the lightest schist in the district, $=2.60$: that of the fault-intrusion, Stob Mhic Mhartuin, $=2.66$. The latter figure gives 2·47 as the density of the same fault-intrusion under ordinary temperatures, but in the glassy condition; *cf.* J. A. Douglas, Quart. Journ. Geol. Soc. vol. lxiii (1907) p. 145. With rising temperatures the difference between the density of the uncrystallized fault-intrusion, merging into true liquid, and that of the solid crystalline quartzite would certainly increase.

occurrence, for the intrusion, when once it had made its way along the fault, must have acted as a far more effective lubricant than the flinty crush-rock which lay alongside of it. It is clear, in fact, that the intrusion retained its fluidity until movement had ceased, for it has crystallized without any marked appearance of fluxion-structure. It can be shown, too, in this same Stob Mhic Mhartuin section, that the flinty crush-rock became rigid, no doubt owing to complete reconsolidation, while the intrusion was still liquid: for, at one point, minute angular fragments of the flinty crush-rock are found embedded, with trifling displacement, in the margin of the fault-intrusion.

There is no difficulty now in understanding why it is that the fault-intrusion invariably shows a chilled margin to the fault-plane, although in the external zone, away from the fault, its margins are sometimes chilled and sometimes not. The cheeks of the fault had in some cases been raised to a very high temperature by friction, before the fault-intrusion had risen into position. But, bearing in mind the small thickness of the fault-rock produced, and that, at the most, we cannot claim more than incipient fusion of even the extreme product (flinty crush-rock), it appears highly probable that the quantity of heat mechanically produced was quite inconsiderable. Once the intrusion had arrived alongside the adherent film of flinty crush-rock, the latter, relieved now of friction and cooled by conduction, would be free to consolidate. In the next stage its temperature would drop to that of the intrusion, which in turn began to solidify and crystallize out. Then both rocks would cool together, yielding, as it were, a composite chilled edge in obedience to the dominant factor of the situation, namely, the conduction of heat away into the cold interior mass downthrown by the fault.

(*b*) Glen Coe and Askja compared.—The walls of the Glen Coe cauldron have long since been planed down by erosion, but we can well imagine that the subsidence was originally marked at the surface by an irregular hollow in the midst of a mountainous country. To-day we can do no more than recognize a few steep slopes of hill and valley, the work of an ancient subaërial erosion, sheltered for ages beneath the vast accumulation of the volcanic pile.

It is probable that the lavas gathered most deeply over the cauldron, but also spread out for some distance over the surrounding country. It is certain, at any rate, from the local variations of the volcanic sequence and from the occurrence of a local assemblage of early irregular dykes, that the sources of supply were near at hand.

When an enquiry is made in Glen Coe as to the possibility of marginal craters having poured forth lavas into the cauldron, the evidence is found to be inconclusive. The early fault-intrusions may have fed many of the hornblende-andesites preserved in the

heart of the cauldron, but the chance of proving such a connexion has been destroyed by the continuation of the movement of subsidence. On the other hand, any subaërial products that may have been supplied by the main fault-intrusion have long since been removed by erosion.

It must also be pointed out, that sources for the great outpourings of augite-andesite and rhyolite, so characteristic of Glen Coe, can nowhere be recognized; if these outpourings were fed from marginal intrusions, their conduits have apparently been obliterated during the final stages of the volcanic history, when the fault-intrusion and the Cruachan Granite came to flood the country.

We had reached this position when Dr. Flett drew our attention to an important paper by Dr. Hans Spethmann[1] on the Askja caldera, 'Iceland's greatest volcano'. Spethmann's descriptions show so clearly that Askja is in many features nothing more than a modern example of a Glen Coe cauldron-subsidence, that it seems advisable to set forth briefly the main conclusions which this author has derived from its study. Askja and Glen Coe, in fact, furnish two most important stages in what Prof. Judd has happily described as a 'denudation series.'

The Askja caldera is a roughly circular hollow, about $4\frac{1}{2}$ miles broad, situated in the midst of a basaltic mountain-mass of subdued swelling form, the Dyngjufjöll (fig. 13, p. 668). The walls of the caldera rise steeply some 1300 feet, measured from their base, and are interrupted only by the valley of the Askja Op, which itself is bounded on both sides by cliffs. Dr. Spethmann regards Askja as a subsidence-caldera, rather than an explosion-caldera, because of the great size of the hollow, and because of the absence of any corresponding pyroclastic accumulation (*op. cit.* p. 403). Round the margin of the subsidence one notices at once the small rim-volcanoes which have poured out basalt in a great flood into the caldera, whence a united stream has issued by way of the Askja Op. These rim-volcanoes we may regard as the local uneroded representatives of the deeply eroded fault-intrusion zone of Glen Coe. As Spethmann puts it, the sinking mass has squeezed up the magma along the marginal fracture (*op. cit.* p. 410).

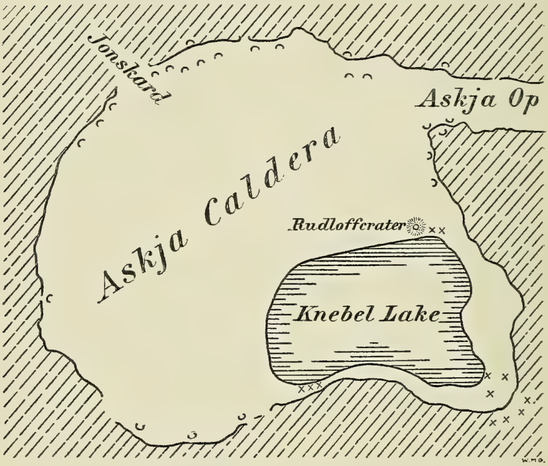
The subsidence of the Askja cauldron dates from late Glacial or post-Glacial times, for the walls of the hollow consist largely of glacio-volcanic products, while the surfaces of the lavas, poured out from the rim-volcanoes, are entirely untouched by glaciation. The previous history of the area is doubtful; but Spethmann believes that the Dyngjufjöll was originally built up as a great shield-volcano of Hawaian type, with its centre corresponding more or less with the centre of the later formed Askja.

Subsequent developments have an added interest, since they have occurred within the last half-century. On March 29th, 1875, a

[1] 'Vulkanologische Forschungen im östlichen Zentralisland' Neues Jahrb. xxvi. Beilage-Band (1908) p. 381.

great eruption took place within the Askja cauldron. The Rudloff Crater was established by explosion, and a great mass of pumice and obsidian hurled forth over the surrounding country. Later, between the visits of W. L. Watts in the summer of 1875 and of Jón Thorkelsson in January, 1876 (Spethmann, *op. cit.* p. 423),

Fig. 13.—*Sketch-map of the Askja Caldera in Central Iceland, after Spethmann, on the scale of about 1 : 90,000.*



[XX = Solfatara; ◡◡ = Rim-volcanoes.]

the Knebel Lake depression, measuring a mile and a half across, was formed by subsidence in the floor of the Askja cauldron. The depth of the hollow is not known with certainty; but, when Johnstrup visited the place in the first year of its existence, he found that the surface of the water in the lake was still 740 feet below the floor of the surrounding Askja caldera. The water was at this time quite hot (40° C.), having been largely supplied by solfataras.

Spethmann points out the obvious connexion between the eruption of the Rudloff Crater and the formation of the Knebel caldera. At the same time he rather lays stress upon the eruption as the c a u s e of the subsidence, since it preceded the latter by an interval of some few months. It is possible, however, to regard the lack of strict synchronism, in this case, as a minor phenomenon,

due to the explosive tendency of the steam occluded in the rising magma, and to treat the Rudloff Crater as a rim-volcano essentially contemporaneous with the Knebel cauldron.

It is particularly interesting to note that, whereas the rim-volcanoes of Askja poured out basalt, the Rudloff Crater brought up obsidian and pumice from the depths. We have, in this, yet another parallel with Glen Coe, where augite- and hornblende-andesite lavas are found together in the closest association with flows of rhyolite.

(*c*) The Etive Granite.—The Cruachan Granite, as exposed at the surface, is divisible into two portions, which are confluent, but still more or less distinct (see fig. 1, p. 614). The one extends northwards into the heart of the Glen Coe cauldron, while the other (including within it the great core of the more acid granite of Starav) forms the main mass of the Etive plutonic complex. The outcrop of aplitic granite forming a strip between Stob Dubh and Meall Odhar emphasizes the individuality of the two lobes of the Cruachan Granite (see Pl. XXXIV). For half its course, to the north-west, it is a marginal intrusion insinuated between the Cruachan Granite on the south-west, and the Schists on the north-east. For the other half of its course, it continues its path south-eastwards without any indication of change, although here it separates merely the two lobes of the Cruachan Granite.

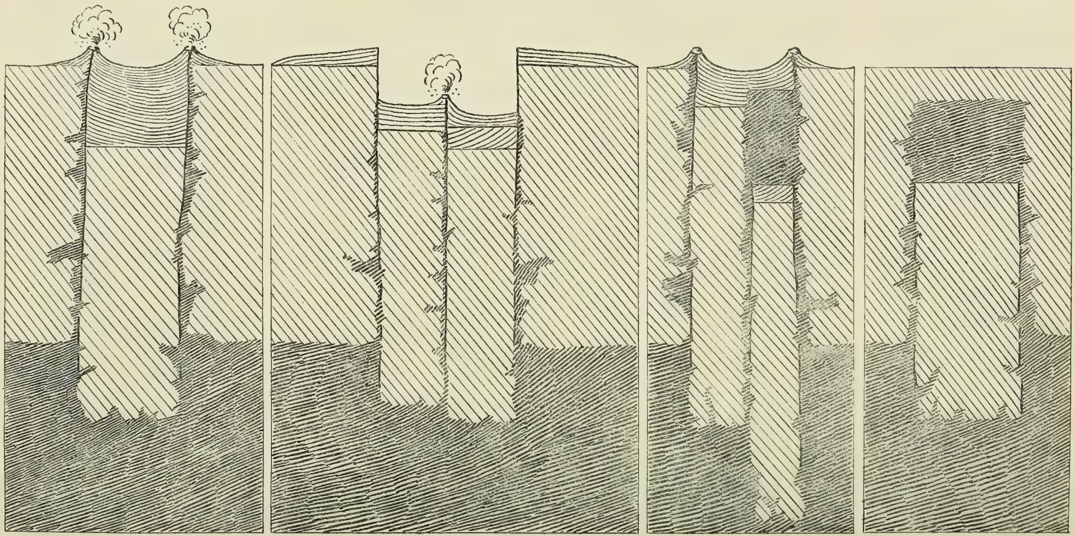
The northern mass, although it must have entered the precincts of the Glen Coe cauldron after subsidence en bloc had ceased, merges with the fault-intrusion in the district of Allt Coire an Easain (p. 635). The interval of respite in the plutonic history of Glen Coe appears, therefore, to have been but brief; at the same time it was sufficiently long to permit of consolidation of the fault-intrusion in certain localities, as at Dalness.

The form of this northern invading mass has only been partly revealed by denudation. All that is exposed to view is the domed roof of a great intrusion which cuts across, but does not tilt, the superincumbent lavas. It is difficult to avoid the conclusion that the invasion of the Cruachan Granite in this instance has not interrupted, so much as modified, the history of subsidence of the Glen Coe cauldron. It appears probable that, since its roof shows no signs of tilting up, its floor must have sunk in order to make room for the invading magma.

But if it be admitted as likely that this semi-detached northern mass of the Cruachan Granite, lying in the Glen Coe area of subsidence, is merely the plutonic infilling of a subterranean cauldron, then it is extremely reasonable to interpret the southern mass in the same manner also. Such a conception is, in fact, in close agreement with Mr. Kynaston's observations.[1] The eastern

[1] 'The Geology of the Country near Oban & Dalmally' Mem. Geol. Surv. 1908, chap. viii.

Fig. 14.—*Diagram illustrating subaërial and subterranean cauldron-subsidences, accompanied by volcanic and plutonic accumulations of igneous rock.*



and the southern margins of the Cruachan Granite are, he says, sharply defined against the schists and easy to follow in the field. These two boundaries are shown by his mapping to be steep and even, and they cannot, therefore, be confounded with a laccolitic margin, but they may readily be interpreted as the approximate edge of a subterranean cauldron. The western and north-western boundary, on the other hand, is of a much more complex type. Here we find the very counterpart of the irregular zone of injection which borders much of the Glen-Coe subsidence. Analogy, therefore, suggests that this intricate fringe is comparable with the fault-intrusion zone of Glen Coe and that it is essentially external to the main mass of the boss with which it is confluent.

Important evidence in certain other directions supports the hypothesis of a subterranean cauldron in the case of the Cruachan boss.

In the first place, at a short distance outside the south-western border of the intrusion, Mr. Kynaston has mapped a remarkable curving fault, approximately conforming for a distance of 10 miles with the rounded boundary of the granite (fig. 1, p. 614). This is certainly not a straight fault subsequently bent by the intrusion of the granite, since the strike of the schists which it traverses shows no corresponding deflection. Its downthrow, though not great, is towards the granite, as is shown by its effect upon the outcrop of a well marked band of lime-silicate hornfels. It is not impossible, therefore, that this fault is a concentric flanking dislocation, tending to enlarge the scope of the subterranean cauldron by downthrow towards its centre.

The next piece of evidence is probably of more importance. It is found, in fact, that the phenomena of the 'early' fault-intrusions of Glen Coe can be paralleled in the history of the Etive boss.

In the south-eastern corner of the Cruachan Granite, Mr. Kynaston (*op. cit.* p. 96) has separated out the older mass of the Beinn a' Bhuiridh intrusion, elongated in form, slightly over 4 miles in length, and measuring half a mile across at its maximum breadth (fig. 1, p. 614). Its outline is strongly curved, in conformity with the margin of the main intrusion; and it is separated from the Highland Schists outside by an almost continuous composite strip, made up of diorite and granite belonging to the later phases of the Cruachan magma. It

'traverses elevated ridges and deep corries alike; it goes up one side of a ridge and down the other side in a manner strongly suggesting the behaviour of a great vertical dyke-like mass. The total vertical thickness of this mass exposed is not less than 2500 feet, while its maximum breadth is half a mile.'

It consists of a complex of andesite, porphyrite and porphyritic gneissose rocks. The whole series shows the effect of contact-alteration by the Cruachan Granite, while the structure of a

notable portion reveals the operation of considerable mechanical stresses analogous to those which affected the granite of Criffel.[1]

'No line can be drawn between the two phases, the normal structure of a fine-grained porphyritic rock, resembling porphyrite or andesite, appearing gradually to pass into a structure indistinguishable from that of a thoroughly foliated rock. . . . The planes of schistosity in the foliated portion are vertical or almost so, and lie parallel to the general line of elongation of the mass.'[2]

We have re-examined Mr. Kynaston's slides, and the evidence of intense shearing accompanied by complete recrystallization is extremely interesting. It is certainly possible that the mass represents a complex 'early' fault-intrusion, sheared and contact-altered during the later subsidence which accompanied the introduction of the main mass of the Cruachan Granite.

But, if there is good evidence for regarding the Cruachan Granite as the infilling of a subterranean cauldron, the same arguments apply in the case of the Starav Granite which occupies the central portion of the boss. Mr. Kynaston has shown that this granite is later than that portion of the Cruachan intrusion which has been preserved as a rim surrounding it on almost every side. As a rule, the boundary between the two is sharp, and the Starav Granite sends small veins into its companion, treating it in this respect as a solid rock. It is probable, in fact, that a considerable interval of time separated the intrusion of the two masses: for, as previously shown, the injection of many, if not quite all, of the porphyrite dykes was accomplished in the interval.

Now, Mr. Kynaston's mapping shows that the boundary of the Starav Granite is a steep or vertical plane.[3] The core of Cruachan Granite which it replaces must, therefore, either have gone up, or gone down. That there has been some movement of the kind is rendered extremely probable, by the fact that

'in many parts of Glen Kinglass [that is, along the south-eastern edge of the Starav boss] . . . the Cruachan granite assumes a well-marked foliated or gneissic structure close to the margin of the coarser, more acid type.'[4]

That the movement was downward, we may readily believe from the analogy of the Glen Coe subsidence lying so short a distance away to the north.

Finally, support is given to the conception of the Etive boss as a subterranean cauldron when attention is paid to the relations of the narrow band of aplitic granite stretching between Stob Dubh and Meall Odhar, which, as already said, is believed to be intermediate in age between the Cruachan and the Starav Granites.

[1] See J. J. H. Teall, 'The Silurian Rocks of Great Britain: vol. i—Scotland' Mem. Geol. Surv. 1899, pp. 609, 610; see also J. B. Hill, for analogous examples in Cornwall, 'Geology of Falmouth & Truro, &c.' Mem. Geol. Surv. 1906, p. 59.

[2] H. Kynaston, 'Geology of the Country near Oban & Dalmally' Mem. Geol. Surv. 1908, p. 96.

[3] We have since made certain of this point in the field.

[4] H. Kynaston, *op. cit.* p. 86; see also footnote, p. 641 of this paper.

The rock constituting this long strip is marked in one locality by thin nearly vertical seams, in which it occurs in a finely sheared granulitic condition (11498). The strike of these granulitic seams is almost the same as that of the band of granite of which they are a part. Certain uncrushed strings belonging to this band also occupy lines of fault, which displace to a small extent thin fine-grained aplite strings belonging to the Cruachan Granite. The inference from these observations is that before and after, and perhaps even during, the marginal uprise of the Meall Odhar intrusion, there was a tendency for the southern portion of the Cruachan Granite to sink along its original northern boundary. This movement was not of great extent, and was discontinued when the conditions of the dyke-phase reasserted their sway. But at a later period, as we have seen reason to believe, the downward movement was resumed, during the intrusion of the Starav Granite, although now it merely affected the central portion of the boss.

In putting forward this interpretation of one particular plutonic mass, we do not wish to insist upon the essential passivity of intrusive magmas in general. The hypothesis which we have advanced is in keeping with the views of Suess, and has much in common with the piecemeal stoping lately advocated by Daly, a hypothesis which we have employed ourselves to account for certain features of the fault-intrusion of Glen Coe. On the other hand, large intrusive masses, entering horizontally stratified formations, are well known to have a marked tendency to assume a laccolitic form; while other manifestations of the disruptive force of magma under pressure might readily be enumerated. It is obvious that any conception of the form of an intrusive mass must be of the nature of an ideal, approached more or less closely, perhaps, but never actually realized, in nature. It must not be imagined, for instance, that we regard fig. 14 (p. 670) as anything more than diagrammatic. In particular we believe that the sinking plugs of solid rock beneath the various cauldrons must become more and more broken up and perhaps dissolved at increasingly lower levels, so that eventually great tubes are formed, consisting largely of molten material.

(*d*) The dykes of Etive.—Two main features call for interpretation in regard to the north-north-easterly porphyrite dykes of the district; first, their regional constancy in direction, and secondly their local concentration with reference to the Etive centre.

The regional constancy in direction of the dykes undoubtedly bespeaks a distribution of earth-stresses different from that which prevailed during the production of either the Glen Coe cauldron or the Etive boss, although possibly in the north-north-eastward elongation of the latter and in its alignment with the Glen Coe cauldron there may be a first suggestion of that orientation of earth-stresses which culminated during the dyke-phase.

We have shown that the introduction of the dykes has been

accompanied by a conspicuous extension of the whole district in a direction normal to their trend. The regional stress thus indicated must clearly have been of the nature of relative tension, or in other words of marked relief of pressure. This, alike assisting and controlling the further introduction of the igneous magma, led to the formation of dykes orientated at right angles to the direction of least compression.

Since the dykes are parallel, the growth of tension in the district must have been repeatedly in the one direction throughout a protracted period. The dykes represent the intermittent response to the growth of the regional stress, and their moderate breadth indicates that, in each case, the tensional earth-stress co-operating with the pressure of the magma was accommodated by a moderate displacement of the walls of the fissure.

Following Marcel Bertrand[1] and Harker[2] we are inclined to seek the cause of this long-continued growth of tension in some widespread contemporaneous depression of a neighbouring portion of the earth's crust. A redistribution of stresses must accompany such a depression; an extensive peripheral region must be involved; and masses which have long been stagnant must stretch and yield, in accordance with the new conditions of equilibrium. Viewed in this light, the dyke-fissures of the Lorne and Glen Coe districts have a distinct analogy with the transverse crevasses of a glacier. An explanation is thus afforded of parallel dykes scattered throughout a large block of country.

If the constitution of the district affected by the regional stress be homogeneous, then the resultant distribution of the dykes should theoretically be uniform. If, on the other hand, there be local differences in the capacity of adjacent rock-masses to resist the stress, then the distribution of the dykes will be correspondingly modified.

In the light of this conception, the local concentration of the porphyrite dykes in relation to the Etive centre can be interpreted with some degree of probability. We have already suggested that beneath the granite exposed at the surface, there extends a tube largely filled with plutonic rocks, which reaches down to the general magma-basin below. Probably the contents of the tube at no great distance down were still molten during the dyke-phase. Indeed, the intrusion of the acid granitic strip between Stob Ban and Meall Odhar intervened in the early portion of this period; while, at a stage which cannot definitely be fixed, but was, perhaps, entirely subsequent to the dyke-phase of activity, the Starav Granite rose into its present position, so as to form the core of the Etive boss at the level now laid bare by denudation. The regional stresses, tending by their action to produce extension,

[1] 'Sur la Distribution Géographique des Roches Éruptives en Europe' Bull. Soc. Géol. France, ser. 3, vol. xvi (1888) pp. 573–617.

[2] 'The Tertiary Igneous Rocks of Skye' Mem. Geol. Surv. 1904, chap. xxv.

would find in this great tube a plastic body, of large cross-section, incapable of resisting deformation. Its weakness would be the dominating subterranean feature of the whole district; its yielding a sufficient cause to locate the two swarms of dykes.

The effect of the pressure of the still molten contents of the tube must not be lost sight of. The material of the dykes was probably injected from the tube, and not directly from the molten reservoir beneath. If the fissures had actually extended down to a general underlying magma-basin, one might have expected to find them frequently accompanied by faulting due to differential sagging, but such is not the case.

In the foregoing pages the volcanic, plutonic, and hypabyssal rocks of Glen Coe have been discussed in the light of a single general principle, namely, the upward movement of igneous magma in correlation with complementary subsidence of portions of the earth's crust.

There are good reasons for believing that, during Lower Old Red Sandstone times, a widespread magma-basin extended at great depth beneath a tract of the earth's surface of which the Scotland of to-day is but a portion. The condition was one of unstable equilibrium, in so far as the magma was lighter than the superincumbent mass of solid rock. Subsidence was the natural response; and where the distribution of tangential stress in the earth's crust was uniform, and where no earlier dominant structure complicated the issue, the subsidence affected circumscribed areas. The cauldron of Glen Coe clearly demonstrates the existence of conditions so symmetrical that no one direction of faulting was more favoured than another.

It is improbable that the cauldron of Glen Coe stood alone in its own day. We have already indicated that the neighbouring Etive boss may be interpreted as an example of a subsidence of closely analogous type, to wit, a subterranean cauldron; and recently evidence has been obtained that, half-a-dozen miles away to the north, the igneous centre of Ben Nevis was pursuing a similar course of development. We may suppose that analogous areas of depression, large and small, were distributed at intervals over the whole region which served as roof to the magma-basin of the period. In fact, the dyke-phase of Etive strongly suggests the growth of one such subsidence in the neighbourhood, a subsidence so vast, so oceanic in scale, that it infringed upon the independence of the smaller local centres. For a time the Etive focus became a peripheral dyke-injector, its development governed by that of its great companion. During this stage, while its sphere of activity was notably enlarged, its individuality was still retained; and subsequently, when the sag towards the neighbouring basin had been compensated and conditions of symmetry had been once

more restored, the Etive centre resumed its independent history of subsidence and intrusion, as exemplified by the uprise of the Starav mass.

In this way an analogy may be detected between the Glen Coe cauldron of Old Red Sandstone times, with its girdle of fault-intrusion, and the Pacific Ocean of to-day, with its fringe of marginal volcanoes. The difference in size of the two is so important that comparison in detail is not admissible. It is possible, however, that the reversal of hade, which can be recognized as a local feature of the Glen Coe boundary-fault, may indicate the beginnings of a peripheral folding, analogous to that which is so conspicuous a feature of the Pacific borders.

Of cauldron-subsidences of the moderate dimensions characteristic of Glen Coe but few modern examples are known. One cause for this may be sought in the explosive activity of steam, which is so important a factor in volcanic phenomena. When igneous magma has been brought within striking distance of the surface, it can often blast a passage for itself. Sir Archibald Geikie and other workers have established the frequency of this type of 'independent' outburst, where volcanoes have arisen without any reference to the existence of fissures at the surface. In such instances subsidence still occurs to compensate for the outpouring of the magma, but a widely distributed sagging without fracture often meets the requirements of the case. In depth, beneath the limit at which the operation of steam as an explosive agent has been traced, it is not unlikely that the phenomena of subsidence and intrusion more frequently approximate to the ideal simplicity which is so closely approached in the cauldron-subsidence of Glen Coe.

EXPLANATION OF PLATES XXXII-XXXIV.

Plate XXXII.

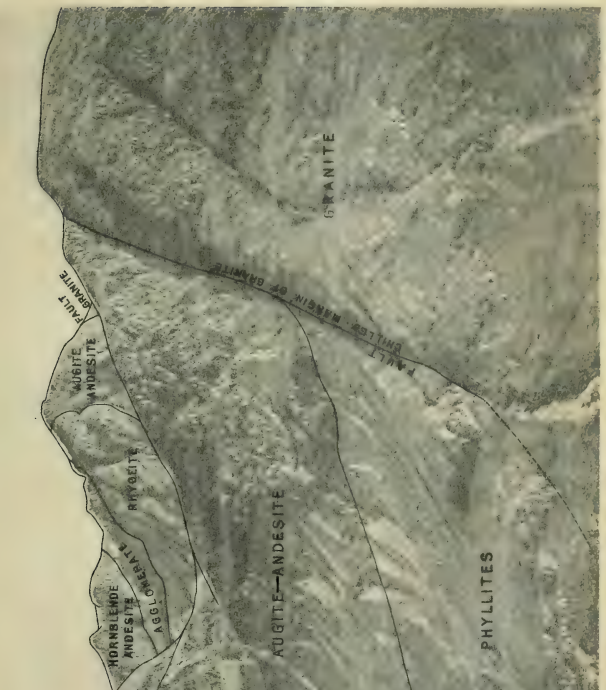
Photograph of Coire nam Beith, Glen Coe, showing the volcanic rocks, which rest upon the Highland Schists, turned up against the boundary-fault. On the other side of the fault, the fault-intrusion, consisting of granite, is chilled against the fault-plane. [Photograph No. 619, Coll. Geol. Surv. Scotl.]

Plate XXXIII.

Horizontal sections through the cauldron-subsidence of Glen Coe, on the scale of 1 inch to the mile (horizontal and vertical). All dykes are omitted.

Plate XXXIV.

Contoured geological map of Glen Coe, on the scale of 1 inch to the mile All dykes are omitted.

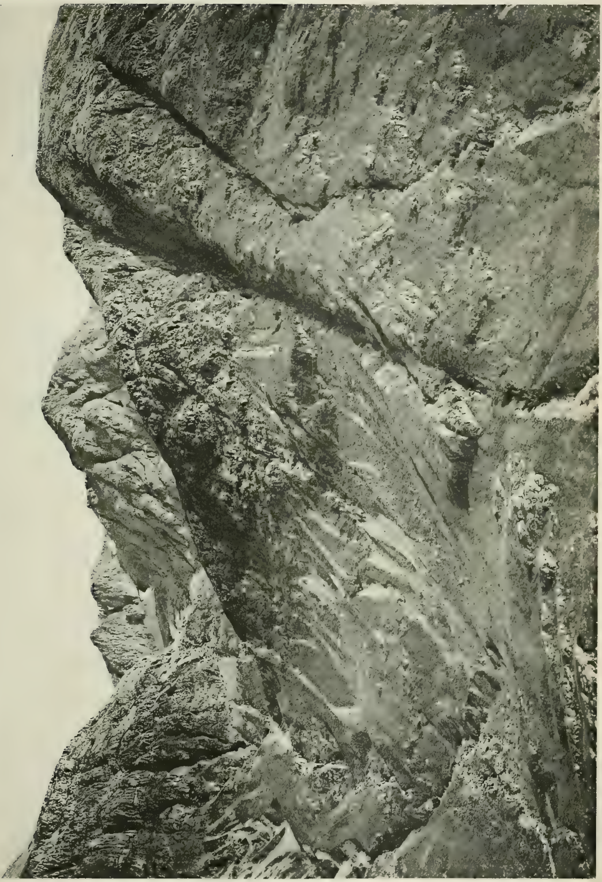


R. Lunn, Photo.

Bemrose, Collo., Derby.

COIRE NAM BEITH, GLEN COE.


PHYLLITES
FAULT
CHILLED MARGIN OF GRANITE
GRANITE
AUGITE—ANDESITE
AGGLOMERATE
ANDESITE
HORNBLENDE
RHYOLITE
RHYOLITE
ANDESITE
AUGITE
FAULT
GRANITE
AGGL



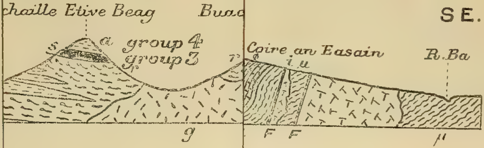
R. Lunn, Photogr.

Bemrose, Collo., Derby.

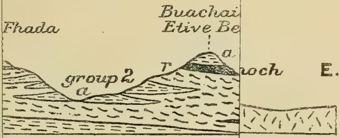
COIRE NAM BEITH, GLEN COE.

RON-SUBSIDENCE OF GLEN TED).

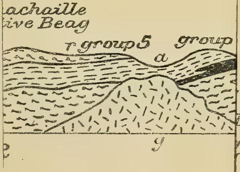
I. *Section from Meall*



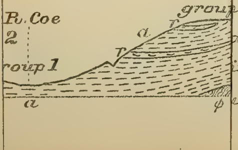
tion through An t-Sron to the



nn Charnan to Stob Mhic M



rough Stob Coire nan Locha



olites

lesites

glomerates
nd Sediments

lt Intrusions

achan and Rannoch
Granites

llites and Pelitic Gneisses

estone

rtzite

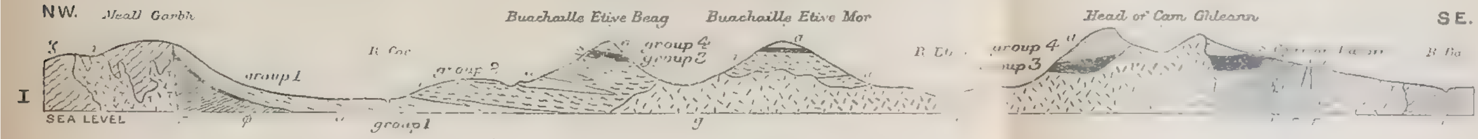
ine Gneisses

lt

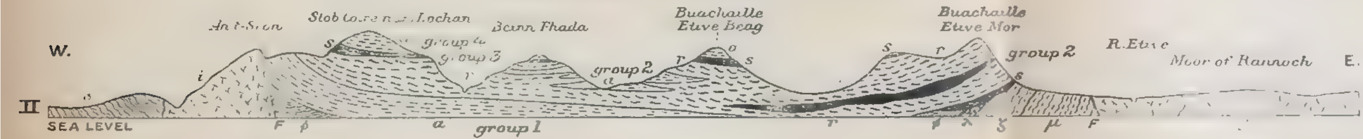
Quart. Journ. Geol. Soc. Vol. LXV, Pl. XXXIII.

Horizontal Sections through the Cauldron-Subsidence of Glen Coe, on the Scale of 1 inch to the Mile (all Dykes are omitted).

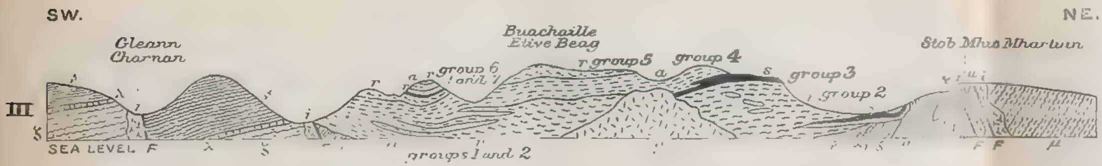
I. *Section from Meall Garbh to the River Ba.*



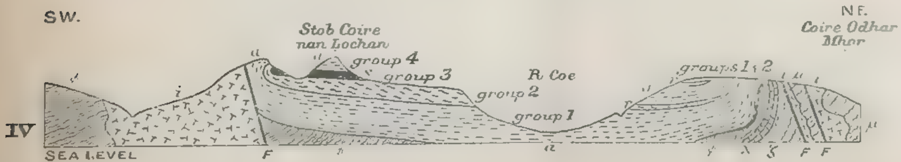
II. *Section through An t-Sron to the Moor of Rannoch.*

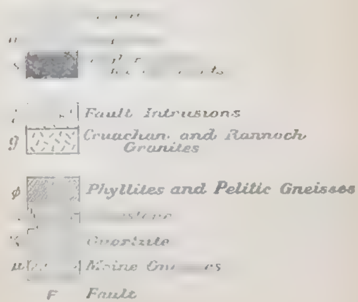


III. *Section from Gleann Charnan to Stob Mhic Mhartuin.*

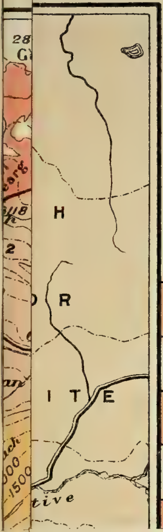


IV. *Section drawn from south-west to north-east through Stob Coire nan Lochan.*



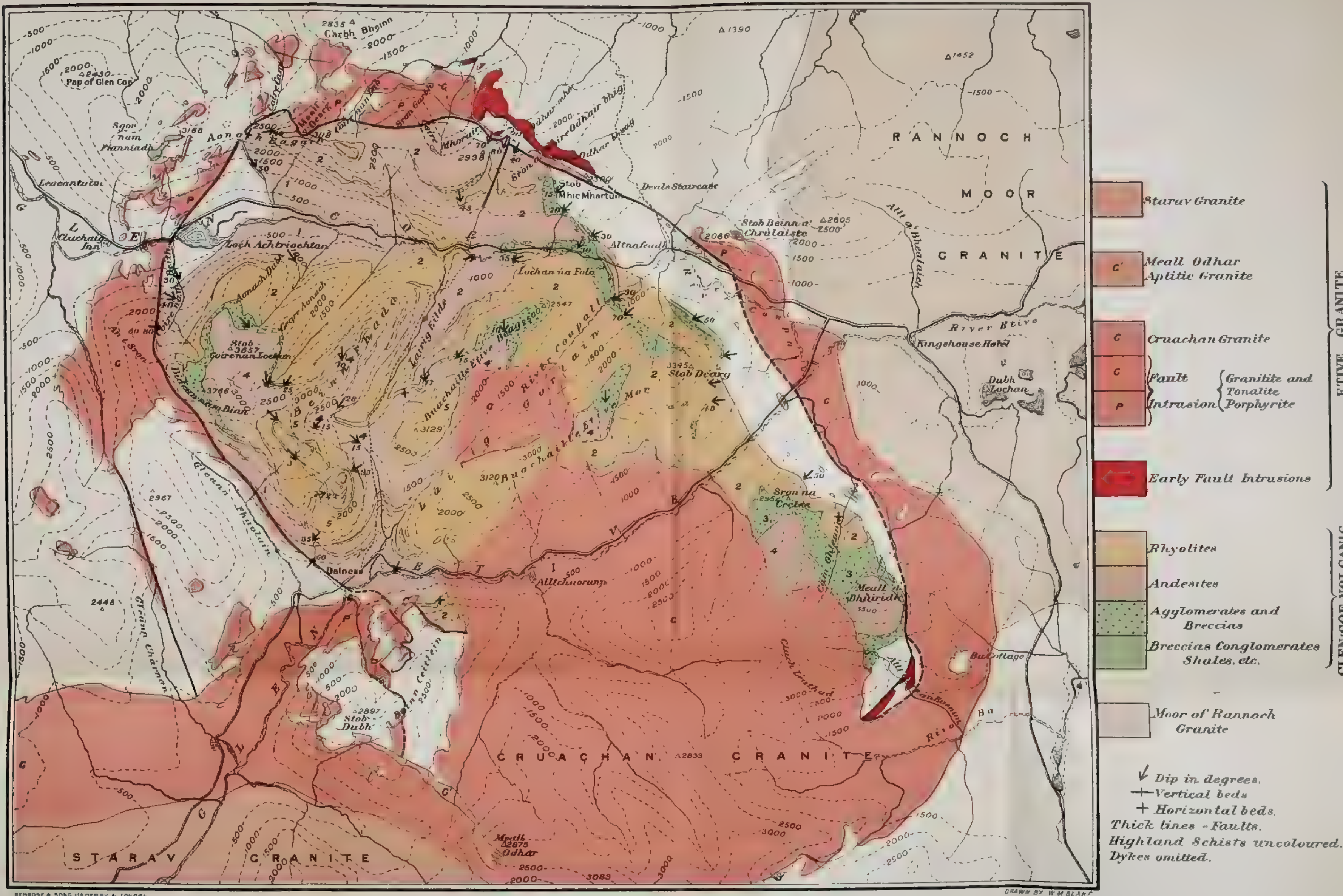


V, Pl. XXXIV.



	Starav Granite
C′	Meall Odhar Aplitic Granite

GRANITE



8 7 6 5 4 3 2 1 0 — 1 — 2 — 3 — 4 Miles

Scale of One Inch to a Statute Mile = 1: 63.360

(The numerals 1 to 5 refer to the lava-groups. See Pl. XXXIII, sections.)

Discussion.

The President (Prof. Sollas) welcomed this paper as another contribution of the first importance afforded by the prolific region of Western Scotland. It was an attempt, marked by great originality, to trace the deeper-seated processes connected with cauldron-inbreaks, of which hitherto the superficial manifestations were better known. The flinty crush-breccias were of great interest, but the evidence so far presented did not seem to prove more than crushing in the first place and injection in the second. To account for the injection by fusion due to the thermal transformation of mechanical energy, seemed in the present instance to be accompanied by many difficulties; and, considering how closely igneous intrusions from below were connected with many of the phenomena under discussion, it might be suggested that an injection of magma might have taken place along crush-planes. It was fortunate that the age of the inbreak relative to the great Caledonian movements could be so definitely determined, and the fact that it followed upon a period of mountain-building seemed to be in harmony with what was known in other cases.

Dr. Teall said that he had examined a small portion of the area under the guidance of the Authors, and could testify to the care and accuracy with which their observations had been made. The surveying of the region had involved the expenditure of a large amount of physical as well as of mental energy.

With regard to the peculiar flinty crush-rocks which he had examined from other districts, he was not prepared to say that there was no admixture of igneous with crushed material; but, if there were any, the amount must be extremely small. He considered that the main theoretical conclusions at which the Authors had arrived were justified by the facts, but he had not yet fully grasped their explanation of the reasons why the dykes were localized in special localities. He regarded the paper as a very important contribution to geological science.

Mr. Barrow congratulated the Authors on the originality of their paper, and was pleased to see that they did not consider all the masses of newer granite necessarily laccolites, the feature of which was that they lifted up the roof of overlying rocks. This did occur in Cornwall, but he had rarely seen any evidence of it in the Highlands. He was inclined to believe that, in some cases at least, they pushed the floor down, which seemed the most likely explanation in the case of the Glen Doll complex. The association of faulting with these great intrusions was the rule rather than the exception, and the phenomenon was best shown by the Glen Doll complex, which lay at the head of Glen Clova, above Kirriemuir, in Forfarshire, and was extremely easy of access. This intrusion lay along the line of the greatest known fault within the Highlands; the fault came up to one edge of the complex, was lost in it, and reappeared on the other side.

He was inclined to differ to some extent from the Authors as to the amount of metamorphism produced by this intrusion. Mr. Maufe had specially referred to the description of the rocks supposed to be altered by the Cruachan Granite. One of these was mentioned as vividly recalling the altered dark schist of Glen Callater, near Braemar. Now, this rock occurred as an inclusion within the Lochnagar Granite, which was a mass some 10 miles in diameter; and it was supposed that the alteration of the dark schist must be due to the granite. The speaker had shown that it could be matched at intervals for a distance of 25 miles from the granite: the crystallization was thus clearly due to the older Highland metamorphism, and the newer intrusion had little or no effect on it.

Mr. E. B. Bailey thanked the Fellows present for their cordial reception of the paper, and especially for their criticisms. In reply to the President, he pointed out that the frequent association, and even occasional minor admixture, of contemporaneous igneous intrusions with the flinty crush-rocks of Glen Coe was of the nature of an accident. In many cases in this same district it could be shown that films of flinty crush-rock originated without the intervention of any igneous action. The independent dynamical origin of flinty crush-rocks had also been demonstrated by Mr. Clough in the Cheviots and in the North-West Highlands, while Sir Thomas Holland had proved the same point in India. In reply to Dr. Teall, he said that the parallel dykes of stretched regions were the counterpart of the parallel folds of compressed regions; while the yielding fluid-filled subterranean cauldrons might be regarded as counter-horsts. Horsts, owing to their rigidity, localized folds; counter-horsts, owing to their weakness, localized cracks, which, filled in contemporaneously with igneous material, gave rise to dykes. In reply to Mr. Barrow, he said that the evidence of extensive contact-alteration, which had been described by Dr. Teall & Mr. Kynaston along the southern and western margins of the Cruachan Granite, was beyond question.

GENERAL INDEX

TO

THE QUARTERLY JOURNAL

AND

PROCEEDINGS OF THE GEOLOGICAL SOCIETY.

END OF VOL. LXV.

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OF

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PAPERS READ.

[No. 261 of the Quarterly Journal will be published next February.]

[The Editor of the Quarterly Journal is directed to make it known to the Public that the Authors alone are responsible for the facts and opinions contained in their respective Papers.]

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